S
627.8
W3w
1982

PLEASE RETURN

The Appendix to Water Storage in the BIG HOLE

A Recommendation

STATE DOCUMENTS COLLECTION

JUN 16 1982

MONTANA STATE LIBRARY
930 E Lyndale Ave.
Helena, Montana 59601

MONTANA DEPARTMENT OF NATURAL RESOURCES & CONSERVATION
WATER RESOURCES DIVISION
MARCH 1982
DNRC

MONTANA STATE LIBRARY
S 627.8 W3w 1982 c.1
The Appendix to Water storage in the Big
3 0864 00039519 7

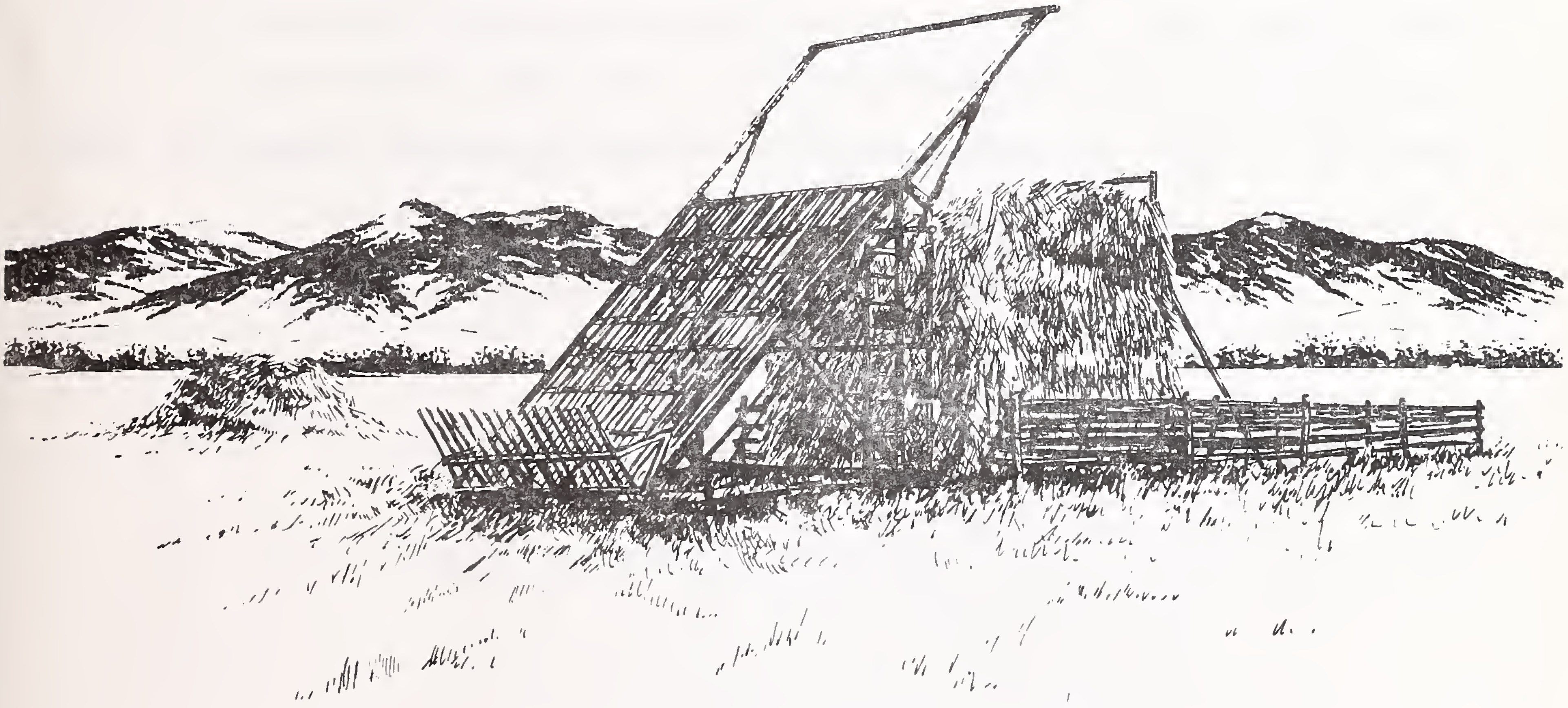
DATE DUE

FEB 4 2004

GAYLORD
PRINTED IN U.S.A

The Appendix to Water Storage in the BIG HOLE

A Recommendation



March 1982

Prepared by the Water Resources Division of the
Department of Natural Resources and Conservation
in response to H.B. 824

ACKNOWLEDGMENTS

The Department of Natural Resources and Conservation would like to acknowledge Gary Fritz and Arnold Vinnard who provided guidance for the Big Hole study; Caralee Cheney who coordinated the study; Mike Kaczmarek of Morrison and Maierle, Inc., who did much of the technical work and wrote the initial report; Glen Smith, Roger Noble, Tom Rediske, and Larry Brown who provided technical assistance; Mark Nicholson, who edited the report; D.C. Howard who prepared the cover illustration; June Virag who prepared the figures; Laurie Zeller and Margie Peterson who typed the report; and William Phippen for proofreading and layout coordination.

TABLE OF CONTENTS

1. Hydrology 1

2. Irrigation Requirements 25

3. Instream Flow Requirements............................. 61

4. Demands and Shortages 69

5. Trail Creek Dam Sites 87

6. French Creek Dam Site 107

7. Johnson Creek Dam Site.................................131

FIGURES

1. Flow of the Big Hole River at Melrose with depleted and undepleted conditions 9

2. Probability of occurrence (and nonoccurrence) of particular average monthly flow rates (in cfs) for July at Melrose 11

3. Probability of occurrence (and nonoccurrence) of particular average monthly flow rates (in cfs) for August at Melrose 12

4. Probability of occurrence (and nonoccurrence) of particular average monthly flow rates (in cfs) for September at Melrose...................................... 13

5. Size of probable maximum flood plotted against a typical drainage area of various sizes...................... 23

6. Hypothetical spills and shortages in the Big Hole basin.. 82

7. Storage versus spills and shortages for the driest 10 years of record above Melrose assuming an existing level of irrigation practices and a low level of aquatic habitat potential 83

8. Annual costs compared to reservoir storage capacity at the Fat Man site on Trail Creek..........................103

9. Reconnaissance geologic map of the French Creek site.........112

10. Reconnaissance geologic map of the Johnson Creek site 136

11. Geologic cross section of the Johnson Creek site............138

12. The relationship between annual costs and reservoir storage capacity at the Johnson Creek site..................161

TABLES

1. Run-off coefficients for the Big Hole River basin 8
2. Comparison of recorded average discharge adjusted to natural average discharge at the Melrose gaging station 10
3. Average annual water supply estimate for the lower Big Hole River basin.. 15
4. Monthly distribution of flows contributed by the lower Big Hole River basin watershed based on 55-year average monthly flow data 16
5. Estimated distribution of average monthly flows at the mouth of the Big Hole River under natural conditions without upstream depletions based on 55-year average flows... 17
6. Irrigable and irrigated acreage in the Big Hole basin which is not economically feasible to irrigate (full or partial supply) from any of the projects considered 28
7. Grass and alfalfa crop coefficients and daylight hours for the modified Blaney-Criddle equation, latitude 45 degrees 30' north of the equator 34
8. Average annual potential evapotranspiration for the upper and lower Big Hole basin............................... 34
9. Estimates of effective precipitation in the upper and lower Big Hole basins 40
10. Estimated soil moisture deficits for the upper and lower Big Hole basins based on current irrigation practices 41
11. Alfalfa and grass water requirements in the upper and lower basins of the Big Hole River (in inches), assuming application of a full water supply............................ 42
12. Recommended farm irrigation efficiencies for surface irrigation application.................................... 44
13. Nonuniform sprinkler efficiency corresponding to irrigation set times for three levels of average irrigation application.. 47
14. Representative hay yields indicated by questionnaire response for the Big Hole River basin 54

15. Costs and revenue per acre for irrigated alfalfa............ 57

16. Low-level and high-level instream flow requirements for the Big Hole River.................................... 64

17. Monthly irrigation diversion requirements compared to average monthly flows in the upper basin............ 69

18. Estimated irrigation water applications in the Big Hole River basin for existing water supplies, levels of irrigation, and crop patterns 70

19. Current irrigation practices in the upper Big Hole River basin, as calculated at the Melrose gaging station..... 73

20. Provision of a full water supply to presently irrigated lands using existing irrigation practices in the upper Big Hole River basin................................. 75

21. Current partial irrigation practices in the Big Hole River basin as calculated for the river at the confluence based on existing irrigated acreages and crops 77

22. Comparison of estimated average monthly shortages for the lower and upper basins under current management conditions, assuming maintenance of a high level of aquatic habitat potential 78

23. Comparison of overall average annual water supply of the Big Hole River basin to the total potential demands for all uses in an average year 80

24. Regulation, irrigated acreage, and costs per acre-foot for reservoir capacities at the Fat Man site............... 89

25. Elevation-storage-capacity data for the Thin Man site on Trail Creek.. 99

26. Relationship between reservoir storage capacity and control of long-term average annual water supply for beneficial use during the ten-year period of low flows at the Fat Man site on Trail Creek...................101

27. Annual costs for different sizes of dams at the Fat Man site...104

28. Regulation, irrigated acreage, and costs per acre-foot for reservoir capacities at the French Creek site 109

29. Elevation-storage-capacity data for the French Creek site ...124

30. Relationship between reservoir storage capacity and control of long-term average annual water supply for beneficial use during the ten-year period of low flows at the French Creek site....................................126

31. Annual costs for different sizes of dams at the French Creek site 128

32. Regulation, irrigated acreage, and costs per acre-foot for reservoir capacities at the Johnson Creek site...........133

33. Unified Soil Classification for engineering purposes.........139

34. Selected engineering properties and relative desirability for various uses for soil groups under Unified Soil Classification..152

35. Elevation-storage-capacity data for the Johnson Creek site...157

36. Relationship between reservoir storage capacity and control of long-term average annual water supply for beneficial use during the ten-year period of low flows at the Johnson Creek site..158

37. Annual costs for different sizes of dams at the Johnson Creek site in terms of dollars per acre-foot.................162

Digitized by the Internet Archive
in 2015

https://archive.org/details/appendixtowaters1982mont

1. HYDROLOGY

PHYSIOGRAPHY

The Big Hole River watershed is located in the Northern Rocky Mountains physiographic province of Fenniman (1931). The land forms are characterized by wide, generally north-south aligned intermountain basins separated by high, rugged, complexly faulted mountain ranges. The north-south aligned mountain ranges are the product of large scale block faulting along high-angle, normal faults and are reminiscent of basin and range structures. The broad, elongated intermountain valleys are fault-bounded, structurally down-dropped basins filled with thick, semiconsolidated to unconsolidated Tertiary and Quaternary sedimentary deposits. The rugged mountainous areas display relatively shallow soils except where thick deposits of unconsolidated debris left by local alpine glaciers support deep soils. The valley floors are multiterraced and exhibit soils generally well suited to agricultural development.

The Bitterroot Mountains to the west, rising to more than 10,500 feet, display aretes, cirques, glacial lakes, and other prominant glacial features. The West and East Pioneer mountains exhibit similar features but are not quite as rugged. The most striking features of the intermountain valleys are the extensive terrace surfaces which extend the length of the valley and grade gently from the mountain fronts to the central river valley or "inner" valley. The terraces are present at several levels and have been modified by dissection and aggradation. The major perennial tributaries exhibit incised, flat-floored valleys as does the mainstem Big Hole River.

In general, the mountainous portions of the Big Hole River basin are forested and the mountain meadow valleys are grasslands and sagebrush. Predominant forest types are lodgepole pine and Douglas fir. At high elevations, localized stands of subalpine fir and spruce are present. Quaking aspen are scattered throughout the lower forested areas. Subirrigated portions of the Big Hole basin floor support grasslands vegetated with Idaho fescue, green needlegrass, needle-and-thread and other native grass hays. Upland terraces are vegetated with cheatgrass brome and needle-and-thread that transitionally grade into sagebrush in the foothill terraces along the mountain fronts and on higher mountain valley terraces.

METHODOLOGY FOR HYDROLOGY

Subbasins of the Big Hole River

The upper basin of the Big Hole River consists of the entire watershed that drains past the U.S. Geological Survey's (USGS) gaging station near Melrose (No. 06025500). This includes the watershed of the Wise River. The lower basin consists of the remaining watershed that drains into the Big Hole River between Melrose and the Big Hole's mouth at the Beaverhead River where USGS has placed another gaging station (No. 06018500). This division reflects the physiographical division of the Big Hole River basin.

Assumptions About Stream Flows

The average annual water supply for the upper basin is calculated using 55 years of stream-flow records collected at the Melrose gaging station (USGS 1974, USGS 1978). For this study, the stream-flow records for the months of irrigation have been adjusted upward to reflect what the flow in the river would be without irrigation diversions. This adjustment was made by adding average annual consumptive use by grass hay in the lands presently irrigated in the upper basin, conveyance losses, and field losses to the recorded stream flow. The study assumed that the acreage of irrigated lands remained constant throughout the 55 years of record, that conveyance losses were 40 percent of diversion requirements, and that field losses were 50 percent of diversion requirements. The study also assumed that any water diverted for irrigation that was not consumed by the crop, lost in conveyance, or lost in the field, returned rapidly to the river as return flow and would be reflected in the measurements at the gaging station.

The adjustment for irrigation diversions was the only one made to the stream-flow records. No adjustment was made for diversions for municipal water use since these were regarded as negligible compared to overall flows. In light of these assumptions, the average annual flow determined in this study must be regarded as an estimate.

About Run-Off Coefficients

In order to estimate the stream flow of an ungaged stream, such as the lower Big Hole, hydrologists use run-off coefficients. A run-off coefficient is the ratio between the precipitation volume of the basin and the stream-flow volume of the basin's stream:

$$\text{run-off coefficient} = \frac{\text{Stream-flow volume}}{\text{precipitation volume}}$$

To find a basin's run-off coefficient, hydrologists first look for a nearby gaged basin that is similar with regard to soil, vegetation, physiography, and precipitation. Then they assume that the ungaged basin's run-off coefficient is the same as the gaged basin's run-off coefficient. To estimate the ungaged basin's stream-flow volume, they multiply its precipitation volume by the run-off coefficient:

$$\text{precipitation volume} \times \text{run-off coefficient} = \text{stream-flow volume}$$

Average annual precipitation in the 2,476-square-mile watershed above the Melrose gaging station ranges from 10 to 70 inches. The precipitation volume calculated for the watershed area above the Melrose gaging station is 3,018,756 acre-feet per year. The adjusted long-term average annual natural flow measured at Melrose for the 54-year period ending in water year 1977 is 1,054,216 acre-feet. Thus, the ratio between the precipitation volume and actual runoff after interception by plant foliage and soil, that is to say the run-off coefficient for the upper basin, is 0.3492 (1,054,216 divided by 3,018,756 = 0.3492).

The run-off coefficients are different for different parts of a watershed because runoff is affected by the intensity and duration of precipitation, foliage type and density, soil types, slope and aspect of the land, existing soil moisture and water table, and many other factors. Preliminary evaluation of the run-off data available for subbasins within the Big Hole River watershed shows that run-off coefficients display a wide range of values. The magnitude of a particular area's run-off coefficient, however, is related to the area's average annual rainfall and to particular characteristics of the area. Based on these criteria, four run-off coefficients are typical in the Big Hole watershed.

Within the Big Hole watershed, mountain meadow valley floor areas and semiarid valley floor areas typically receive an average of less than 18 inches of precipitation annually. The mountain meadow valley floor areas are generally well saturated due to annual irrigation and shallow ground-water conditions. Consequently, these areas produce relatively large amounts of runoff per unit of precipitation volume. On the other hand, the semiarid valley floor areas have gentle to moderate slopes, have moderate to rapidly permeable soils, and are generally densely vegetated with grass and low bushes. These areas intercept a larger proportion of precipitation and so produce less runoff per unit of precipitation volume.

Mountainous areas in the Big Hole watershed typically receive an average of 18 to 60 inches of precipitation annually. Because these areas are forested, display moderate to very steep slopes, have permeable to slowly permeable soils, and have relatively little ground vegetation cover, these areas produce relatively larger amounts of runoff per unit of precipitation volume.

The major type of bedrock supporting soil-bedrock complexes further influences the run-off coefficients in the mountainous areas. Areas underlain predominantly by granitic intrusive rock and related border zone gneisses display the combined characteristics of slope, soil type, exposed bedrock area, vegetation, and other factors that result in surprisingly high ratios of runoff per unit of precipitation volume.

The portion of watershed above the Wise River gaging station (No. 06024590) is representative of a nongranitic mountainous run-off zone receiving the large amounts of precipitation typical of a mountainous area. Granitic mountain terrain is mostly found in the northwestern portion of the Big Hole watershed in the mountainous portions of the Trail Creek, Tie Creek, Johnson Creek, Plimpton Creek, and Pintlar Creek watersheds.

The run-off coefficients calculated for the Big Hole River basin are shown in table 1. The mountain meadow valley floor run-off coefficient of 0.3696 is derived from the overall basin coefficient of 0.3492 calculated at Melrose by using watershed area-weighted values for the other run-off coefficients compared to the area-weighted value at Melrose. The semiarid valley floor run-off coefficient is based on watershed yield maps prepared by the Soil Conservation Service for a nearby comparable area.

The average annual water supply for the watershed between Melrose and the mouth of the Big Hole River is determined by applying the run-off coefficients from table 1 to the measured areas of the appropriate terrain-precipation zones in the watershed. The average annual discharge is divided into average monthly discharge values by prorating the average annual values against real gaging records for the Birch Creek station (No. 06026000) and adjusting the prorated values to long-term averages derived from the 55-year record at Melrose.

TABLE 1: Run-off coefficients for the Big Hole River basin.

Average Annual Precipitation (in inches)	Terrain Classification	Run-off Coefficient
8 - 18	Semiarid valley floor	0.2256
8 - 18	Mountain meadow valley floor	0.3696
18 - 70	Nongranitic mountain	0.3192
18 - 70	Granitic mountain	0.4482

UPPER BASIN SUPPLY

Stream-flow records from the Melrose gaging station indicate an average annual water supply of 842,500 acre-feet for the upper Big Hole River basin. This figure, however, does not take into account depletions due to irrigation. The upper Big Hole's adjusted average annual water supply, which includes estimated depletions due to irrigation, is 1,058,591 acre-feet. Table 2 shows recorded and adjusted average discharges. Figure 1 shows recorded and adjusted average discharges as well as the average depletions due to irrigation in acre-feet.

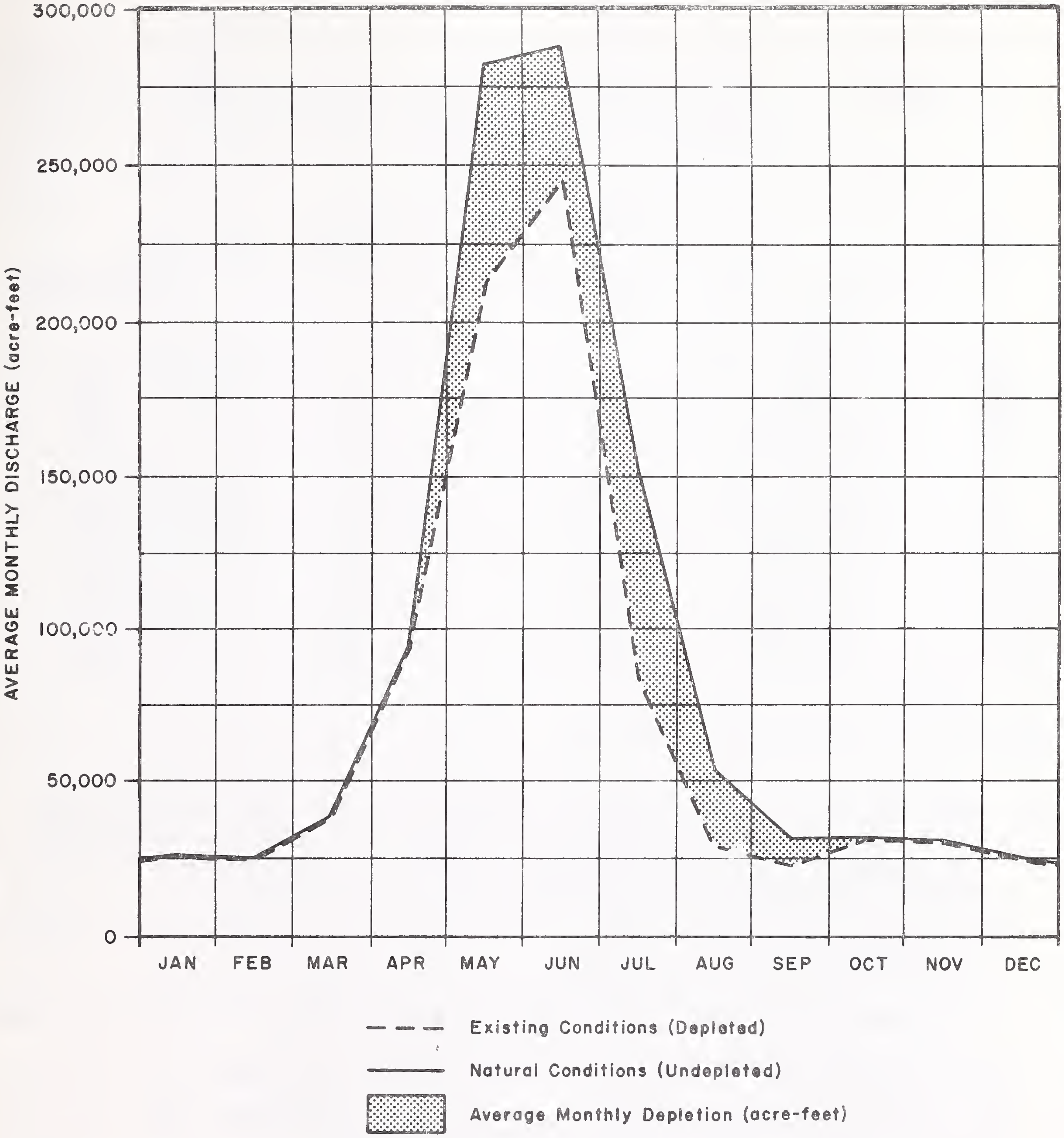


FIGURE 1. Flow of the Big Hole River at Melrose with depleted and undepleted conditions. (All values in acre-feet.)

TABLE 2: Comparison of recorded average discharge adjusted to natural average discharge at the Melrose gaging station.

Month	Average Monthly Discharge Acre-feet Recorded*	Acre-feet Adjusted** to Natural	Cubic Feet/Second Recorded*	Cubic Feet/Second Adjusted** to Natural
Jan	21,555	21,555	351	351
Feb	20,447	20,447	368	368
Mar	27,849	27,849	453	453
Apr	91,821	91,821	1,543	1,543
May	212,522	284,371	3,456	4,625
Jun	245,702	289,558	4,129	4,866
Jul	83,957	151,331	1,365	2,461
Aug	29,886	53,812	486	875
Sep	22,792	31,803	383	534
Oct	31,252	31,252	508	508
Nov	30,201	30,201	508	508
Dec	24,591	24,591	400	400
Annual	842,575	1,058,591		

* Recorded average annual discharge consists of actual recorded flow for 55 years of record. The total of 842,575 acre-feet exceeds the 842,500 acre-foot average due to dam failure flow and other corrections to mean flow calculations.

** Adjusted flow is estimated by adding estimated depletions to existing flow.

Figures 2, 3, and 4 indicate the probability of occurrence (and nonoccurrence) of particular average monthly flow rates (in cfs) for July, August, and September, respectively, at Melrose under existing conditions (i.e., the losses due to irrigation diversions have not been added into these flow rates). Because these probabilities are for a monthly average value, the reader should remember that day-to-day flow rates may differ significantly from these monthly averages.

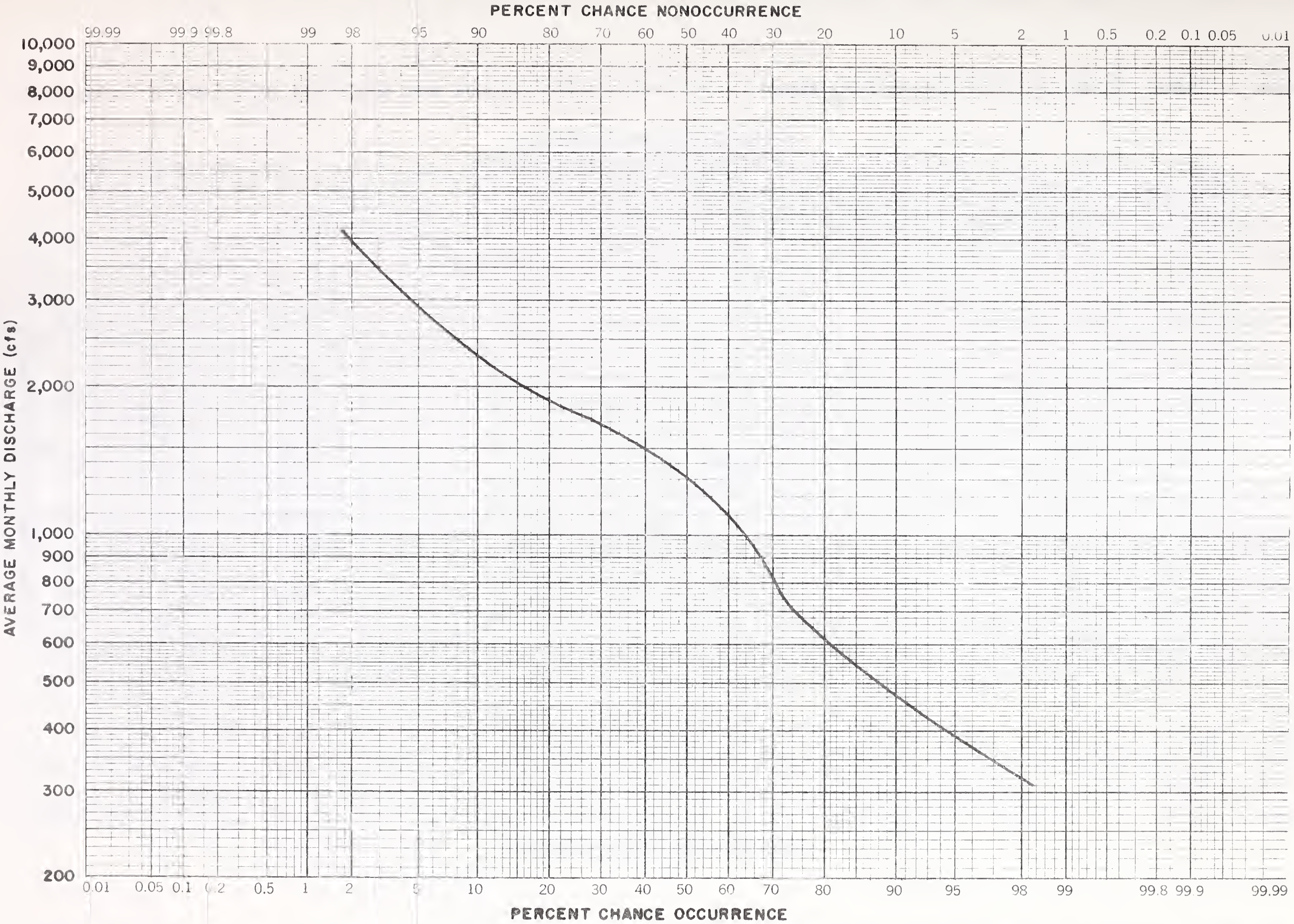


FIGURE 2. Probability of occurrence (and nonoccurrence) of particular average monthly flow rates (in cfs) for July at Melrose.

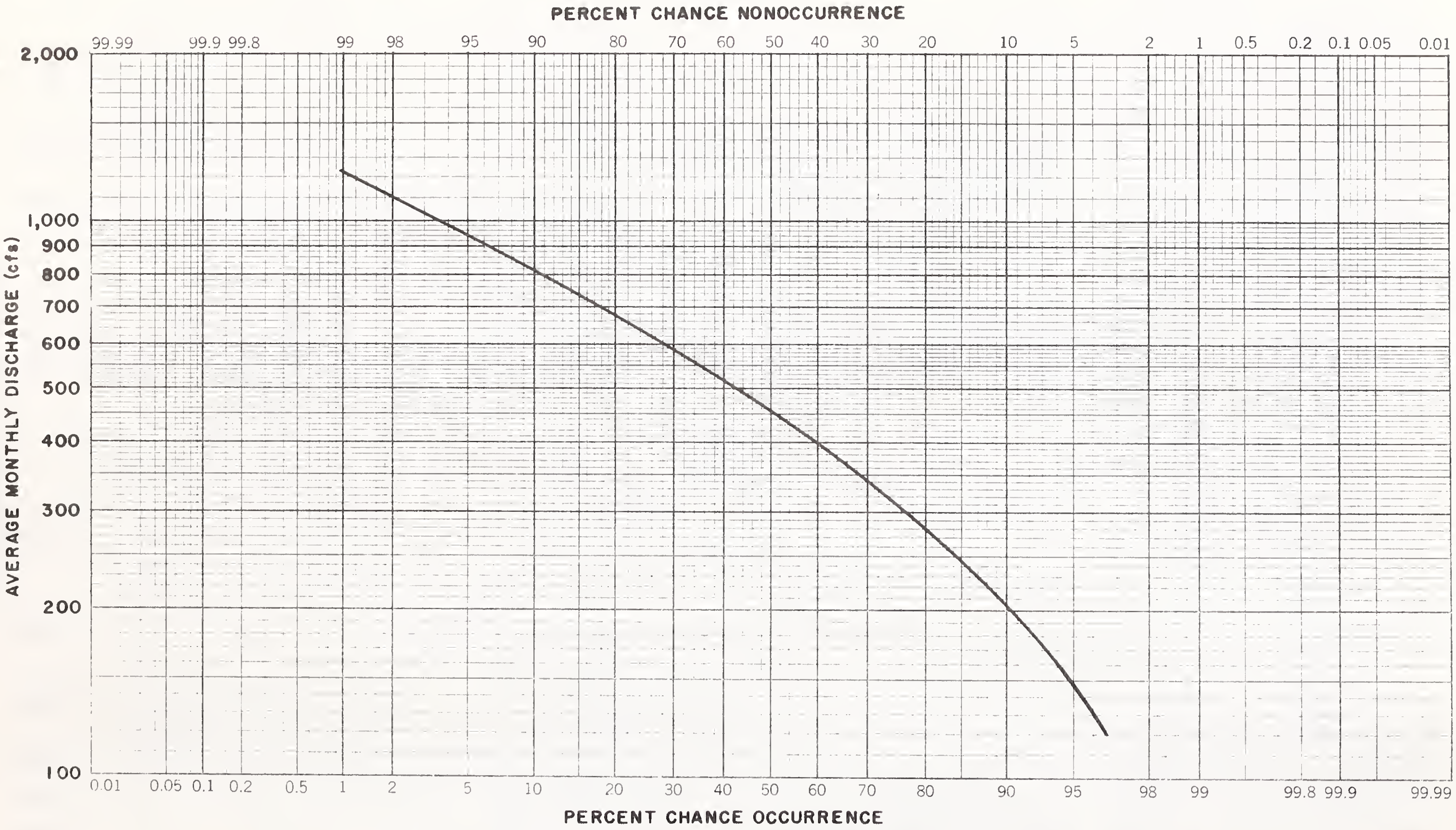


FIGURE 3. Probability of occurrence (and nonoccurrence) of particular average monthly flow rates (in cfs) for August at Melrose.

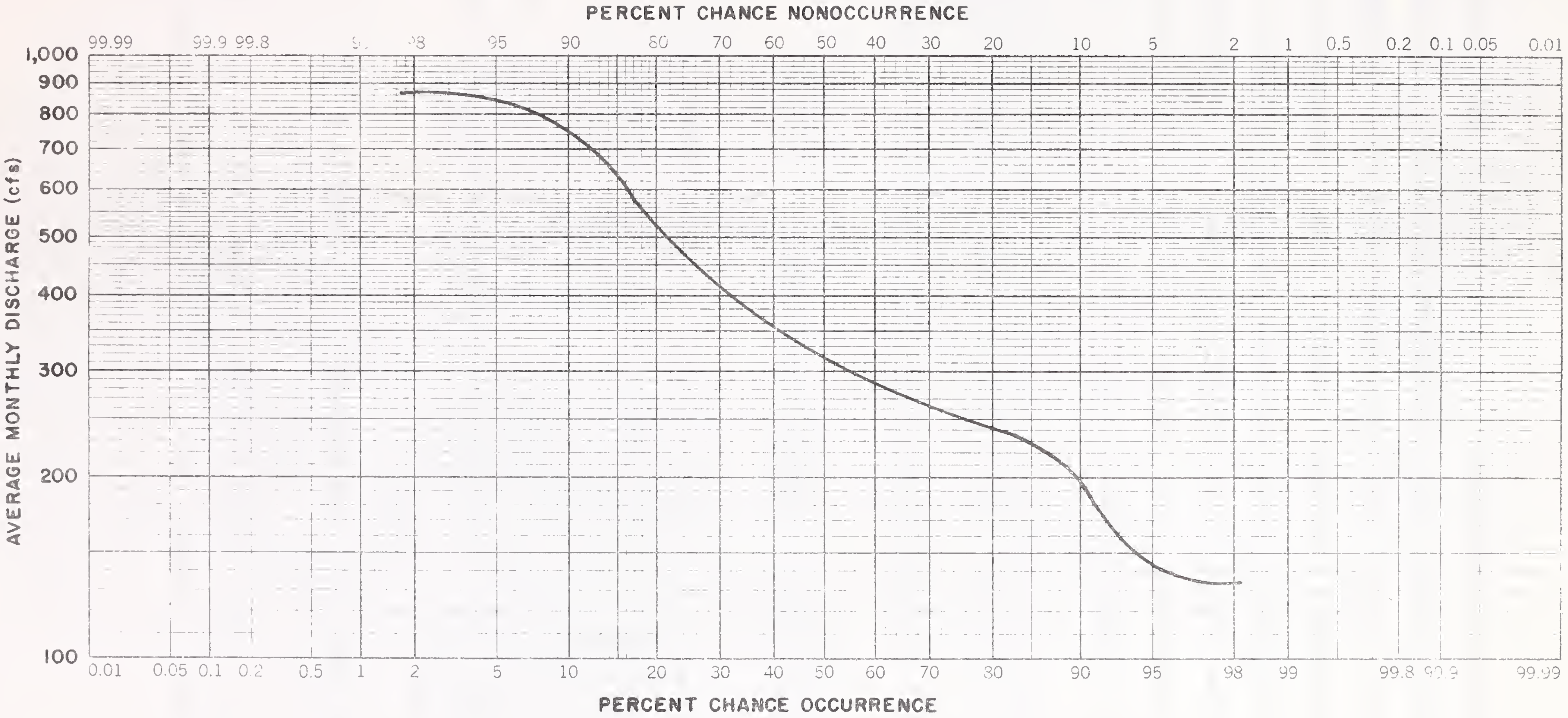


FIGURE 4. Probability of occurrence (and nonoccurrence) of particular average monthly flow rates (in cfs) for September at Melrose.

These curves can be used to determine the probability of satisfying a particular average instream flow-rate requirement during any of the months of any particular year. For example, the probability of satisfying a particular average instream flow rate requirement of 600 cfs in July in any single year is .81 or 81 percent. Another way of thinking about this is that during a 100-year period, a flow rate requirement of 600 cfs will be met in 81 years and will not be met in 19.

The reciprocal of the probability is called the recurrence frequency. For example, the recurrence frequency for a 600 cfs flow rate would be 1/.81 or 1.23.

LOWER BASIN SUPPLY

The lower basin contributes a long-term estimated annual average of 73,782 acre-feet to the Big Hole River. This brings the total average annual water supply at the mouth of the river to 1,132,372 (assuming the adjustments for losses due to irrigation diversion in the upper basin). The data used to determine the lower basin's contribution are shown in table 3.

Since the lower basin is ungaged, the average monthly flow distribution of the yearly supply in the lower basin is determined by comparison to other gaged streams in the lower basin. The records selected for simulation of long-term average monthly flow conditions in the lower basin are those for the Birch Creek Station (No. 0600260) in water years 1965 through 1970. The Birch Creek watershed most closely represents the climatological conditions and aspect of the lower basin compared to other available stream-flow records. Table 4 shows the five-year average monthly flows for Birch Creek and the five-year average monthly flows as adjusted to the 55-year long-term average monthly flow distribution. The percentage of average annual adjusted flow in Birch Creek that is contributed by each adjusted monthly value is used to apportion the river's average annual flow of 73,782 acre-feet on a monthly basis.

TABLE 3: Average annual water supply estimate for the lower Big Hole River basin.

Precip. Zone (inches)	Average Precip. (feet)	Zone Area (miles)	Precip. Volume (acre-feet)	Runoff Coefficient (percent)	Average Annual Runoff (acre-feet)
8-10	0.750	96.47	46,305.6	0.2256	10,446.7
10-12	0.917	59.18	34,731.6	0.2256	7,835.6
12-14	1.083	35.87	24,862.2	0.2256	5,609.0
14-16	1.250	34.88	27,904.0	0.2256	6,295.3
16-18	1.417	15.68	14,219.9	0.2256	3,208.1
18-20	1.583	14.13	14,315.4	0.3192	4,569.5
20-30	2.083	22.74	30,315.2	0.3192	9,676.6
30-40	2.917	22.60	42,191.5	0.3192	13,467.5
40-50	3.750	11.02	26,448.0	0.3192	8,442.2
50-60	4.583	4.52	13,257.7	0.3192	4,231.9
			TOTAL		73,782.4

TABLE 4: Monthly distribution of flows contributed by the lower Big Hole River basin watershed based on 55-year average monthly flow data.

	Birch Creek Flows*		Percent	Lower Basin Flows*	
Month	5-year** Average	55-year Average	Annual Average	Average Annual	Average Monthly
Jan	450	403	2.00	73,782	1,476.7
Feb	337	326	1.62	73,782	1,194.6
Mar	400	430	2.14	73,782	1,575.6
Apr	606	699	3.47	73,782	2,561.3
May	3,657	3,507	17.42	73,782	12,850.5
Jun	7,462	6,641	32.98	73,782	24,334.3
Jul	3,719	3,481	17.29	73,782	12,755.3
Aug	1,813	2,014	10.00	73,782	7,379.8
Sep	708	703	3.49	73,782	2,576.0
Oct	1,096	930	4.62	73,782	3,407.7
Nov	751	677	3.36	73,782	2,480.7
Dec	343	324	1.61	73,782	1,187.2
TOTAL	21,342	20,135	100.00		73,779.7

* All flows are in acre-feet.
** Water years 1965-1970.

The seasonal fluctuations in flow at the mouth of the Big Hole River are similar to those at the Melrose gaging station. The average monthly flow distribution at the mouth of the river based on the 55-year average monthly flows is shown on table 5.

GROUND WATER

Very little factual information has been developed regarding the distribution, availability, and quality of ground water in the upper Big Hole River basin. Information published by the State of Montana in 1934 (Perry 1934) is of reconnaissance level, largely speculative in nature, and questionable as to some of its conclusions in view of the more recent data regarding ground-water conditions in the intermountain valleys of southwestern Montana. The availability of large quantities of ground water for development in the upper Big Hole basin would provide a potential alternative to tributary storage of surface water for relieving existing and future water shortages.

TABLE 5: Estimated distribution of average monthly flows at the mouth of the Big Hole River under natural conditions without upstream depletions based on 55-year average flows.

Month	Average Flow (Acre-feet)	(cfs)
January	23,032	375
February	21,642	390
March	29,425	479
April	94,382	1,586
May	297,222	4,834
June	313,892	5,275
July	164,086	2,669
August	61,192	995
September	34,379	578
October	34,660	564
November	32,682	549
December	25,778	419
TOTAL	1,132,372	

The distribution, availability, and, to a large extent, the quality of ground water in the upper Big Hole River basin is doubtlessly influenced directly by the nature of the intermountain basin fill deposits, as is the case in other intermountain basins in southwestern Montana. A general evaluation of the geologic conditions that influence ground-water resources in the upper Big Hole River basin is best provided by evaluating the basin in terms of what is presently known regarding nearby basins of similar geologic history and characteristics.

The depth to bedrock in the upper Big Hole River basin is not known. Perry (1934) speculates that, "In the center of the basin, the hard rock floor may be 500 or more feet below the present land surface." In comparison, a combination of test well data and gravimetric surveys indicates at least 1,640 feet and possibly 2,000 feet of semiconsolidated and unconsolidated sediments are present over bedrock in the nearby Bitterroot basin to the north (McMartrey et al. 1972). Gravimetric data in the nearby Deer Lodge basin indicate depths of valley fill ranging from more than 5,500 feet near Anaconda to about 2,300 feet near Deer Lodge (Konizeski et al. 1968). The factor influencing the depth to bedrock common to all the intermountain basins is the displacement along the faults that created the structural bedrock basins.

Investigation of the valley fill materials in the nearby basins has revealed some overall characteristics common to all the valley fills that bear directly on the distribution and availability of ground water. The valley fill materials of the intermountain basins in southwestern Montana consist of relatively thick sequences of Tertiary sedimentary deposits overlain discontinuously by relatively thin deposits of Recent alluvium. The Recent alluvium is generally highly productive for high-capacity wells of 500 to 1,000 gallons per minute (gpm) or more but is limited in distribution to the lowest valley floor area commonly referred to as the inner valley, and to active stream valleys. The Recent alluvium ranges from 20 feet (Konizeski et al. 1968) to 40 feet (McMartrey et al. 1972) in thickness.

Tertiary sedimentary deposits which form the major portion of the valley fill typically display a three-part subdivision in the uppermost 200 to 500 feet of material. Uppermost Tertiary deposits along the basin margins often consist of coarse-grained colluvial materials, including talus, that grade into coarsely bedded piedmont fans of sand and gravel. The coarse colluvial and alluvial deposit are a potential source of large amounts of ground water from high-capacity water wells in some locations and should yield water of good chemical quality.

Further out from the basin margins, the coarse-grained colluvium and piedmont fans grade into fine-grained deposits of interbedded sand, silt, and clay that represent floodplain deposits of the ancestral river drainages in the Tertiary valleys. The floodplain deposits are saturated with ground water but are not favorable to construction of high-capacity water wells due to the poor permeability of the fine-grained materials.

The fine-grained floodplain deposits generally grade into interbedded channel gravel and sand near the central parts of the basins where the ancestral Tertiary rivers aggraded back and forth across the inner valley of the Tertiary basins that were filling up with sediments. Similar channel deposits are present at the mouths and along buried portions of major tributaries in the Tertiary valleys. The channel deposits provide excellent potential to develop high-capacity water wells providing water of good chemical quality.

Deeper, older Tertiary deposits may consist of semiconsolidated conglomerate, mudstone, sandstone, shale, and freshwater limestone with little or no potential to yield ground water. Ground water in the older Tertiary deposits may be of poor chemical quality. The older Tertiary deposits may be exposed along the basin margins due to erosion and are present at various depths in the central part of the basins depending on the extent of post-Tertiary erosion.

The foregoing concepts of the valley fill geology of the intermountain basins apply in general to the upper Big Hole River basin. Only within the past ten years have water wells begun to penetrate significant portions of the Tertiary valley fill sediments in basins adjacent to the upper Big Hole River basin. Water wells ranging in depth from 500 to 1,000 feet are producing as much as 1,000 gpm or more of good quality ground water from Tertiary sediments for agricultural and industrial uses. However, the distribution and hydraulic properties of the Tertiary ground-water aquifers are still largely unknown and construction of high-capacity test wells or production water wells in most of the intermountain basin valley fill areas remains a high-risk venture. The presence of extensive Tertiary piedmont gravels in the upper Big Hole River basin combined with considerable recharge potential from the surrounding mountain terrain suggests that excellent potential exists to successfully complete high-capacity water wells in the upper Big Hole River basin.

FLOOD FLOWS

Although flows and recurrence frequency of flood events are of little value in comparing water supplies to water demands, many of the potential tributary storage sites evaluated in this report are situated so as to present high hazards to downstream life and property. This is an important aspect of any storage project since a reservoir must not only provide water, but it also must be safe.

High-hazard dams must conform to criteria (US ACE 1975) requiring emergency spillways to be adequately sized to pass the probable maximum flood (PMF) at the site.

Spillway construction costs are a major, if not overriding, consideration in total dam construction costs. In order to estimate the magnitude of PMF events for subbasin areas in the Big Hole River basin, a plot of PMF peak flows versus drainage area size was developed (figure 5). A separate curve of PMF volume versus drainage area was also plotted on figure 5. The PMF curves on figure 5 are based on detailed PMF event studies conducted in western Montana for high-hazard dam safety inspections for DNRC and the Army Corps of Engineers by Morrison-Maierle, Inc. The PMF curves provide a quick way to estimate PMF events for subbasins in the Big Hole River basin.

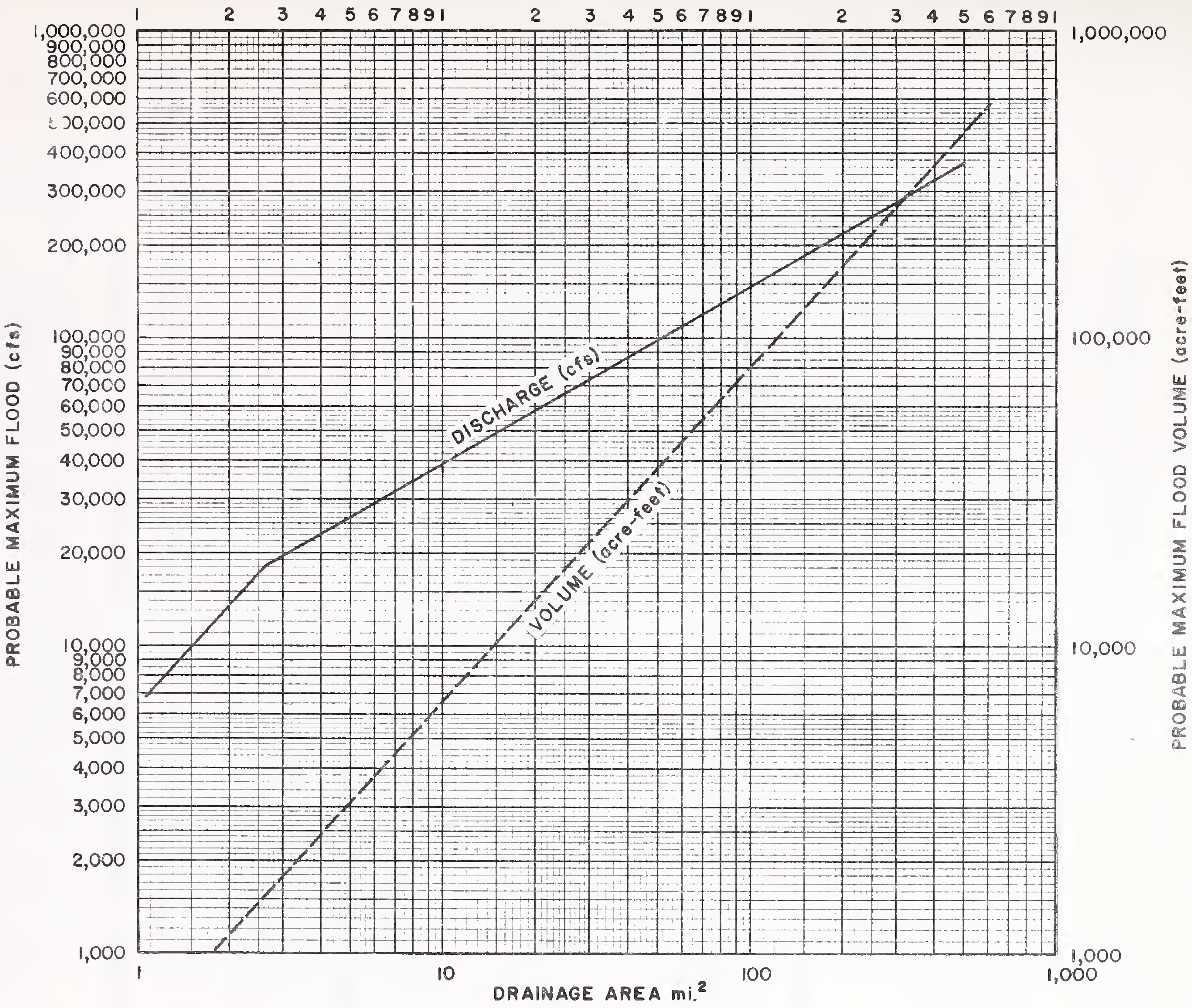


FIGURE 5. Size of probable maximum flood plotted against a typical drainage area of various sizes.

REFERENCES

Fenniman, N.M., 1931. Physiography of western United States: New York, McGraw-Hill Co., Inc., 534 pp.

Konizeski, R.L., McMartrey, R.G., and Brietkrietz, Alex, 1968. Geology and ground water resources of Deer Lodge Valley, Montana: U.S. Geol. Survey Water-Supply Paper 1862, 55 pp.

McMartrey, R.G., Konizeski, R.L., Johnson, M.V., and Bartells, J.H., 1972. Geology and Water Resources of the Bitterroot Valley, southwestern Montana: U.S. Geol. Survey Water-Supply Paper 1889, 80 pp.

Perry, E.S., 1934. Physiography and groundwater supply in the Big Hole Basin, Montana: Montana Bureau of Mines and Geol., Mem. No. 12, 18 pp.

U.S. Army Corps of Engineers, 1975. Office of the Chief of Engineers report to the U.S. Congress, National program of inspection of dams: Vol. 1, Appendix D, Dept. of the Army, Washington, D.C.

U.S. Geological Survey, 1978. Water resources data for Montana: Data Report MT-78-1, U.S. Dept. of the Interior.

U.S. Geological Survey, 1974. Surface Water Supply of the United States, 1966-1970: U.S. Geol. Survey Water Supply Paper 2116.

2. IRRIGATION REQUIREMENTS

INTRODUCTION

In view of the lack of definitive information regarding annual diversion, depletions, and return flows associated with irrigation in the Big Hole River basin, estimates of the irrigation water requirements were developed from other sources of information. Although the methodology and data used in developing the irrigation water requirements are precise methods based on recorded information, the calculated irrigation water requirements cannot take into consideration differences in irrigation practices by individual irrigators or different topography. Until actual measurements of irrigation diversions and depletions based on field measurements are compiled, the calculated irrigation water requirements as used in this report must be regarded as the best estimate available. The calculated irrigation requirements reflect estimated needs and are not intended to represent actual use.

IRRIGABLE LAND

The DNRC reconnaissance land classification survey was the basis for determining the irrigable land in the Big Hole basin. The land classification survey was designed specifically to establish suitability of land for sustained irrigation farming. The objective was to outline the land areas that have a potential for irrigated agriculture.

The land classification survey separates the land areas into (1) lands having potential for irrigation termed "irrigable" in contrast to (2) the inferior "nonirrigable" lands which are unsuited for present or future irrigation because of unfavorable characteristics. The term "irrigable land" as used in this reconnaissance classification includes lands that have soil, topography, and climate that will support sustained irrigated agriculture with proper water management, drainage, and other necessary conservation practices.

Lands which are classified as irrigable are divided into classes on the basis of their relative suitability for irrigation farming. Class 1 represents irrigable land with potentially high productive value, class 2 represents land of intermediate value, and class 3 includes land of the lowest value that may be suitable for irrigation. Water supply and economics are not considered.

The irrigated land was identified from water resource surveys for Beaverhead County which were mapped using aerial photography with a minimum of field checking. The accuracy of this land classification and irrigated land mapping is general reconnaissance level. It is important to understand that any project development should be based on a detailed study to pinpoint the exact location and limits of the land best suited for irrigation.

The results of these land-classification and irrigated-land surveys are printed in table 6. These surveys covered the entire Big Hole basin, but for this study, DNRC assumed that only irrigable land downstream from proposed storage sites, within a 200-foot lift and within 1-1/4 miles from the mainstem would be able to receive stored water and so benefit from any storage project. However, all irrigated acres were considered for present water diversion requirements.

TABLE 6: Irrigable and irrigated acreage in the Big Hole basin which is not economically feasible to irrigate (full or partial supply) from any of the projects considered.

Area	Land Class 1	Land Class 2	Land Class 3	Irrigable	Irrigated
Headwaters to Mudd Creek					
Above study area	0	0	8,728	8,728	3,804
Above 6,500 feet	0	0	13,589	13,589	17,805
North Fork above Trail and Johnson Creek	0	0	3,323	3,323	1,781
Thompson Creek	0	0	0	725	725
Mussigbrod Creek	0	0	0	2,072	2,072
Pintlar Creek	0	0	926	926	5,560
York Gulch	0	0	475	475	290
Mudd Creek	0	0	250	250	497
Total Headwaters to Mudd Creek	0	0	27,291	30,088	32,534
Mudd Creek to Maiden Rock					
Fishtrap Creek	0	0	1,140	1,140	1,094
Calvert & Stewart Creek	0	0	550	550	1,917
High Benchland	0	0	1,350	1,350	0
East Fork LaMarch Creek	0	0	0	0	540
Johnson Creek	0	0	0	0	180
Twelve Mile-Sullivan Creek	0	0	2,310	2,310	0
Divide Creek	0	0	2,426	2,426	886
Moose Creek	0	0	0	0	225
Total Mudd Creek to Maiden Rock			7,776	7,776	4,842

Table 6 (continued):

Area	Land Class 1	 3	 3	Irrigable	Irrigated
Maiden Rock to Gaging Station					
High benchlands	0	0	4,594	4,594	0
Trapper Creek	0	0	0	569	569
Camp Creek	0	0	235	235	331
Rock Creek	0	0		144	458
Total Maiden Rock to Gaging Station			4,829	5,542	1,358
TOTAL Upper Big Hole	0	0	39,896	43,406	38,734
Lower Big Hole Areas Outside 200-Foot Limit Gaging Station to Reichle Dam					
Willow Creek	0	0	0	0	142
Birch Creek	0	0	0	0	9,323
Total					9,465
Reichle Dam to Beaverhead				0	0
TOTAL Lower Big Hole				0	9,465
TOTAL Big Hole Basin				43,406	48,199

IRRIGATION DIVERSION DATA

Data collection efforts for this study included interviews with ditch company authorities to determine the amount and distribution of irrigation diversions. It was determined that the ditch companies do not measure or record their diversions. One exception was the Pageville Ditch Company in the lower Big Hole River basin where the Bureau of Reclamation took miscellaneous measurements of discharge in the ditch in 1976. The miscellaneous measurements show that the ditch carries about 144 cfs when it is in full operation. The measurements do not reveal the amounts diverted by farm irrigators or the amounts of operational tailwater return. The lack of information regarding ditch company diversions did not pose a problem to this study.

Irrigation diversion requirements and estimates of individual irrigator's current diversion practices were, in part, determined on the basis of a questionnaire developed by DNRC. The questionnaire recipients were limited to water users on the mainstem river downstream from Wisdom (and on the North Fork) whose irrigated acreages constitute about 23 percent of the identified acreage presently being irrigated in the basin.

METHODOLOGY FOR DETERMINING IRRIGATION REQUIREMENTS

This section defines several terms and concepts necessary for understanding the methodology used to determine irrigation requirements.

Crop Water Requirements

Crop water requirement is the basis for determining irrigation water requirements. "Crop water requirement" is synonymous with "consumptive use" and "evapotranspiration." Crop evapotranspiration (or consumptive use) is defined as the quantity of water consumed by crops in photosynthesis and evaporated from soil surfaces. Potential evapotranspiration is a basic factor in determining irrigation water requirements and is the maximum amount of water that can be beneficially used by the crop in food production. Establishment of crop water requirements for less than potential evapotranspiration results in limitations of crop productivity. Water in excess of potential evapotranspiration cannot be used beneficially in photosynthesis and may contribute to shallow ground water conditions.

Potential evapotranspiration of crops is determined in the field by measurements of actual water use with scientific instruments, such as lysimeters or neutron probes. The methods are complex and beyond the scope of this discussion. Because these field measurements are expensive, they require carefully controlled data collection and are almost exclusively made at agricultural experiment stations. There are only a few locations in the western United States where long-term measurements of evapotranspiration have been observed and collected. Measurements of evapotranspiration have not been conducted in the Big Hole basin.

Researchers studying irrigation have developed many equations for the estimation of potential evapotranspiration in areas where measurements are not available. The equations use climatic factors including temperature, solar radiation, humidity, and wind speed. The equations are adjusted by numerical coefficients to reflect differences in evapotranspiration by different crops.

Examples of these equations include the Penman, the Jensen-Haise, the Blaney-Criddle, and the Thornwaite methods. These methods are discussed and evaluated by the American Society of Civil Engineers (September 1973). This study used the modified Blaney-Criddle method.

The Blaney-Criddle method was one of the earliest methods developed to determine evapotranspiration and it has been modified by the Soil Conservation Service (SCS 1970). The modified equation is as follows:

$U = kc\ (kt)\ f$

where:

U = monthly evapotranspiration in inches

kc = crop growth stage coefficient

$kt = .0173t - .314$

t = mean monthly air temperature in degrees Fahrenheit

$f = (t \times p)/100$

p = monthly percentage of daylight hours in the year

Monthly crop coefficients developed from monthly percentage of daylight hours developed for latitudes 45 to 46 degrees north (SCS 1970) were used in this study. Table 7 shows the monthly percentage of daylight hours and monthly crop coefficients.

Table 8 shows estimates of potential evapotranspiration, in other words, the total yearly water needs of a particular crop. Temperature data for the last 43 years at Wisdom and the last 48 years at Dillon were used (NOAA 1978). Precipitation and temperature data for the Twin Bridges-Whitehall area of the lower Big Hole River are incomplete. The continuous records at Dillon, including norms, however, represent nearly the same climatic conditions at Whitehall and Twin Bridges, with differences only in the individual timing of local hydrologic events. Thus, the use

TABLE 7: Grass and alfalfa crop coefficients and daylight hours for the modified Blaney-Criddle equation, latitude 45 degrees 30' north of the equator.

Month	% Daylight Hours Per Year	Crop Coefficients, kc Alfalfa	Grass
January	6.37	.63	.51
February	6.52	.73	.59
March	8.29	.86	.69
April	9.10	.99	.79
May	10.35	1.08	.87
June	10.50	1.13	.91
July	10.61	1.11	.89
August	9.77	1.06	.85
September	8.43	.99	.79
October	7.60	.91	.73
November	6.40	.78	.63
December	6.10	.64	.51
TOTAL	100.04	10.91	8.76

TABLE 8: Average annual potential evapotranspiration for the upper and lower Big Hole basin (in inches).

	Lower Basin		Upper Basin	
Month	Alfalfa	Grass	Alfalfa	Grass
January	0.03	0.02	0.00	0.00
February	0.15	0.12	0.00	0.00
March	0.42	0.34	0.10	0.08
April	1.47	1.18	0.90	0.73
May	3.14	2.52	2.25	1.81
June	4.64	3.73	3.54	2.84
July	6.53	5.24	4.81	3.86
August	5.38	4.32	3.78	3.04
September	1.71	1.38	1.96	1.57
October	1.45	1.16	0.90	0.72
November	0.37	0.30	0.16	0.13
December	0.09	0.07	0.00	0.00
TOTAL	25.38	20.38	18.40	14.78

of records from Wisdom and Dillon should accurately represent conditions in the study area.

Detailed consideration of evapotranspiration is justified on the basis of the relationship with crop yield. Substantial research is not available for a variety of crops and a variety of locations, but researchers have found for some crops that yield is directly proportional to evapotranspiration (Hanks 1974). Also, yields do not level off or flatten out until potential evapotranspiration levels are reached. It is to the advantage of the irrigator, therefore, to deliver water sufficient to satisfy potential evapotranspiration and allow maximum yield per unit of land.

Leaching Requirements

Depending on the quality of irrigation water and soil chemistry, application of water beyond the crop water requirement may be required. This additional water can remove undesired chemicals that buildup in the crop's root zone. This removal of chemicals is called leaching. The undesirable chemicals are deposited by the plant and they accumulate if they are not removed. By applying additional water for leaching, these chemicals are dissolved and migrate in solution away from the crop root zone.

The water quality of the Big Hole River and its tributaries is such that it does not cause an unusual buildup of soluble salts in the soil. Thus, little more than minimal leaching is required.

Current irrigation practices apply water in excess of crop water requirements which leach chemicals from any relatively permeable soil. In fact, it appears that farm irrigation efficiency losses satisfy the leaching requirements for most soil and water conditions in the Big Hole basin.

Farm Irrigation Water Requirements

In order to provide that portion of the crop water requirement needed from irrigation, a farm application system is necessary. Examples of farm application systems include contour ditch, border dike, rill, and sprinkler. Because each of the farm application systems is not totally perfect in delivering only the amount of water needed by the crop, some water is lost in application and the amount of water available to the irrigation system must be greater than the crop water requirements. The farm water requirement is the amount of water needed by the farm irrigation system to satisfy crop water requirements. It might also be defined as the amount of water to be delivered by canal, pipeline, or other conveyance system to the edge of the field where irrigation application takes place.

The efficiency of a farm application system is the basis for determining the farm irrigation requirement. For a crop to utilize irrigation water it must be made available to the root zone of the plant. Efficient application of water to the root zone requires that water be applied at a rate slow enough to allow water to enter the soil. Also, the duration of the irrigation must be such that the moisture-holding capacity of the soil within the root zone is not exceeded. The crop root zone is the area of soil, generally ranging from 2 to 6 feet in depth, depending on crop, from which the crop is effective in drawing water. Deep percolation is the amount of water which exceeds the moisture-holding capacity of the soil in the crop root zone and consequently migrates to depths below the crop root zone. Soil moisture capacity is the amount of water held by the soil within the crop zone when the soil has been saturated and water percolating downward by gravity has drained away.

Generally, contours, ditches, rills, and borders are less efficient in the application of water than sprinkler systems. From the edge of the field to the crop root zone, more water is lost to surface runoff or deep percolation using surface irrigation methods than with sprinkler irrigation methods. Farm irrigation efficiency is expressed as a percentage and is the portion of water delivered to the edge of the field that is used to satisfy crop requirements.

Water applied by the farm irrigation system and not utilized by the crop is either permanently or temporarily lost to the source of supply. If the source is a stream, for example, excess water may be discharged back to the stream either as surface water runoff or ground-water return. In either case, the returning water is called return flow. Some water migrating back to a stream system or an aquifer may be intercepted by the root zone of noncrop vegetation and consumed. In the case of sprinkler irrigation, some water is lost to wind and spray evaporation even before reaching the ground. Return flow is the water not utilized by the irrigated crop or noncrop vegetation that reenters the source of supply and is available for use. In the case of return flows to a stream, the return flows are available for downstream diversion. In the case of return flows to an aquifer, the return flows add to ground-water storage and are available for pumping. The time required for migration of return flows may range from hours to many months. Beneficial consumptive use is that portion of the water delivered to the field which is utilized by a crop for the beneficial production of food and fiber.

Nonbeneficial consumptive use is that portion of the water diverted for irrigation which is consumed by noncrop vegetation, evaporated from free water surfaces, or lost to wind and spray evaporation (in the case of sprinklers). Total consumptive use is the sum of beneficial and nonbeneficial consumptive use. Depletion is the amount of water permanently lost to a source stream or aquifer including total consumptive use and that portion of return flows captured by adjacent streams or nontributary subsurface formations.

Effective Precipitation

Effective precipitation is a source of water to supply crop evapotranspiration requirements. It reduces irrigation requirements. Factors affecting total effective precipitation (Sprinkler Irrigation Association 1975) are:

1) total precipitation
2) intensity of precipitation
3) intake rate of soil
4) water-holding capacity of soil
5) evapotranspiration rate of the crop, and
6) timing of precipitation in relation to irrigation.

The Soil Conservation Service (1970) has developed a method for estimating effective precipitation and this method was applied to the precipitation data from Wisdom and Dillon for the period May through September for the period of record. The results are shown in table 9.

TABLE 9: Estimates of effective precipitation in the upper and lower Big Hole River basins (in inches).

Month	Upper Basin	Lower Basin
May	1.13	1.11
June	1.43	1.56
July	0.61	0.68
August	0.73	0.63
September	0.70	0.60
TOTAL	4.60	4.58

Soil Moisture Deficit

Although evapotranspiration during the period from October through April is generally small, losses in soil moisture for the period may exceed effective precipitation, resulting in a loss of soil moisture. The difference between soil moisture at the end of April and the soil moisture capacity is termed the soil moisture deficit. This deficit must be made up by irrigation water at the beginning of the irrigation season. On the basis of the questionnaire data, a soil moisture deficit of 1.63 inches has been calculated for the upper basin and 2.39 inches for the lower basin under current irrigation practices. The calculations are shown in table 10.

TABLE 10: Estimated soil moisture deficits for the upper and lower Big Hole basins based on current irrigation practices (in inches).

	Upper Basin (grass)	Lower Basin (alfalfa)
Potential evapotranspiration	14.78	25.38
Applied water	-5.32	-16.82
Effective summer precipitation	-4.60	-4.58
Unsatisfied evapotranspiration	4.86	3.98
Effective winter precipitation	-3.23	-1.59
Soil moisture deficit	1.63	2.39

Total Crop Irrigation Requirements

Table 11 summarizes irrigation water requirements for alfalfa and grass in the upper and lower basins. These figures assume that the potential evapotranspiration requirements of the crops are satisfied on an average annual basis. Questionnaire replies show that the upper basin suffers shortages of water for full irrigation in midsummer of most years and that the lower basin suffers shortages one year in three. The predominant irrigated crop in the upper basin is grass, while alfalfa is the predominant crop in the lower basin.

TABLE 11: Alfalfa and grass water requirements in the upper and lower basins of the Big Hole River (in inches), assuming application of a full water supply.*

	Upper Basin	
	Alfalfa	Grass
Potential evapotranspiration	16.34	13.12
Effective precipitation	-4.60	-4.60
Initial soil moisture deficit	0	0
Leaching requirement	0	0
Irrigation requirement	11.74	8.52
	Lower Basin	
	Alfalfa	Grass
Potential evapotranspiration	21.40	19.59
Effective precipitation	-4.58	-4.54
Initial soil moisture deficit	2.39	2.12
Leaching requirement	0	0
Irrigation requirement	19.21	17.17

* Initial soil moisture deficit depends on the amount of water applied and so increases with increasing shortages in irrigation water. (USDA 1967.)

Farm Irrigation Efficiency

The efficiency of water delivery from the edge of the irrigated area to the root zone of the crop is highly variable depending on the method of application, the crop, the terrain, and irrigation management. The two basic methods of irrigation application in Montana are surface irrigation and sprinkler irrigation. Surface irrigation includes contour ditches, rills, furrows, spreader systems, and border dikes. Sprinkler irrigation includes center-pivot, hand-move, and side-roll systems.

Surface Irrigation Efficiency

Surface irrigation methods are generally 40 to 60 percent efficient depending on the type of surface irrigation, the slope of the irrigated land, and soil characteristics. Table 12 summarizes surface irrigation efficiencies for a variety of methods currently in use. The data in table 12 are based on conditions of good irrigation management.

Border irrigation is the most efficient means of surface irrigation under favorable soil conditions, and efficiencies of 70 percent can be achieved under midrange soil conditions. Irrigation by contour ditch is the most common means of surface irrigation for hay crops. Efficiencies range from 35 to 60 percent depending mainly on the slope of the irrigated area. An efficiency of 50 percent is a reasonable expectation for irrigation by contour ditch for most soils, for moderate slope, and for close management of the irrigation set times.

TABLE 12: Recommended farm irrigation efficiencies for surface irrigation application.*

Application System	Slope	Favorable Soils	Midrange Soils	Unfavorable Soils
Level border	0.00%	90%	70%	50%
Graded border	0.05	80	70	65
	1.00	65	60	55
	5.00	60	55	50
Furrow	.1	70	70	70
	1.0	65	65	65
	1.5	60	60	60
Contour-ditch	.5- 1.0	60	55	45
	1.0- 4.0	55	50	40
	4.0-12.0	45	40	35

*Data interpreted from SCS (1974), pp. 5-10 to 5-13.

SPRINKLER IRRIGATION EFFICIENCY

Sprinkler irrigation efficiency is influenced principally by wind and spray evaporation losses, nonuniform sprinkler distribution, and management of the irrigation set times to match soil water requirements.

Wind and spray evaporation losses were investigated by researchers in Arizona (Frost and Schwalen 1955). It was found that wind and spray evaporation losses are dependent on a variety of factors including:

1) relative humidity
2) air temperature
3) sprinkler nozzle diameter
4) sprinkler nozzle pressure, and
5) wind velocity.

Wind and spray evaporation losses take place between the sprinkler nozzle and the ground surface where droplets of water are evaporated. Wind and spray losses are an unavoidable inefficiency of sprinkler irrigation systems. The efficiency of sprinkler irrigation from the nozzle to the ground is 95 percent for the average conditions expected in the Big Hole River upper and lower basins based on the method of Frost and Schwalen (1955).

Even under ideal conditions, sprinkler precipitation is not uniform in its pattern. Nonuniform sprinkler irrigation results in water deficiencies in some areas and surplus water in other areas of the field. If the irrigation set time is lengthened to increase the water supplied to areas of deficit, excess water is applied to areas that have received an adequate water supply. Excess water in those areas enters the ground-water system or is surface runoff.

Previous researchers (Hart and Reynolds 1965) have developed methods for relating the percentage of an area adequately irrigated with sprinklers to irrigation set times and irrigation efficiency. The application of the methodology requires knowledge of characteristics of the sprinkler nozzle, wind conditions in the area, and the spacing of nozzles in the field. Manufacturers of sprinklers have developed a characteristic known as the uniformity coefficient which serves as an index of the consistency of sprinkler application for various equipment and field conditions. Hart and

Reynolds (1965) utilized the uniformity coefficient in deriving the relationship for sprinkler efficiency.

For sprinkler equipment with moderately good performance, the relationships between set time and nonuniform sprinkler efficiency are demonstrated for various average applications in table 13.

Table 13 shows that nonuniform sprinkler efficiency decreases as the percentage of the area receiving adequate irrigation increases. For example, with an average application of 1.8 inches, a set time of 9.41 hours provides the required water supply to 70 percent of the area under sprinkler and the irrigation efficiency is 82 percent. However, to supply adequate water to over 95 percent of the area, a set time of 13.91 hours is required, and nonuniform sprinkler efficiency drops to 58 percent.

TABLE 13: Nonuniform sprinkler efficiency corresponding to irrigation set times for three levels of average irrigation application.*

	Average Sprinkler application (inches)			
Irrigation set time (hours)	1.8	3.0	4.0	
Percentage of area adequately irrigated				Nonuniform sprinkler efficiency
95	13.91	23.20	30.95	58
90	12.05	20.09	26.80	67
85	11.04	18.43	24.59	72
80	10.37	17.29	23.07	76
75	9.84	16.41	21.90	79
70	9.41	15.70	20.94	82

*Based on methodology of Hart and Williams (1965) and sprinkler rate of .22 inches per hour.

Management of irrigation set times is largely a balancing of practical considerations with soil conditions. Due to labor requirements, irrigation set times of 12 and 24 hours are often used. Occasionally, eight-hour sets are practical in soils with low water-holding capacity. From table 13, selection of practical set times would vary depending on the irrigation requirements for the particular soil.

For 1.8 inches of irrigation, a 12-hour set would be practical resulting in a nonuniform sprinkler efficiency of 67 percent. For 4.0 inches of irrigation, a 24-hour set would be practical resulting in a nonuniform sprinkler efficiency of 72 percent.

Nonuniform sprinkler efficiencies of 80 percent and higher are possible if irrigation equipment is properly selected, irrigation set times are carefully selected and practical, and soil conditions are not variable. An application efficiency of 70 percent is considered reasonable for good management conditions.

Net sprinkler irrigation efficiency is the product of wind and spray efficiency (95 percent) and nonuniform sprinkler efficiency for practical management (70 percent) for an average efficiency of 66 percent.

The discussion of sprinkler efficiency relates to hand-move and side-roll systems which require manual changing of the irrigation system. Center pivot irrigation systems, which operate automatically and continuously, are slightly more efficient. Net sprinkler irrigation efficiency for center pivot systems of 70 to 75 percent is considered adequate.

DELIVERY SYSTEM EFFICIENCY

Efficiency of the delivery system, from the source of supply to the farm irrigation system, is dependent primarily on the design of the conveyance system and the distance from the diversion point to the farm. Conveyance systems are constructed as unlined earthen canals, lined canals, or pipelines. Unlined canals are the least costly and the most inefficient; pipelines are the most costly and the most efficient.

In both lined and unlined canals, losses leading to inefficiencies are principally attributable to seepage through the bottom of the canal. Evaporation from the water surface and evapotranspiration from riparian vegetation is generally small in comparison to seepage losses. Evaporation and seepage losses in pipelines are usually negligible.

Delivery efficiencies may range from 50 percent to 90 percent. Examples of delivery efficiencies on existing projects are occasionally less than 50 percent. Occasionally, efficiencies exceed 90 percent on projects of several thousand acres or more. Field inspection of delivery systems in the Big Hole basin suggests a wide range of efficiencies. Ditches diverting water from tributaries display seepage in numerous places and cross considerable distances of relatively permeable materials susceptible to deep percolation losses. Efficiencies in many of the longer tributary diversions may be 50 percent or less.

Diversion ditches in the inner alluvial valley of the Big Hole River are generally associated with shallow ground-water conditions or are situated so that seepage losses return to the river very quickly. The conveyance system efficiencies of diversions from the mainstem may exceed 60 percent in many cases. In places where mainstem diversions are inefficient, return flows reach the river so rapidly that the lower efficiencies generally do not affect net river depletions.

An average conveyance efficiency of 60 percent is used in this report for delivery systems in the Big Hole River basin. The delivery system efficiency of 60 percent was used by the Bureau of Reclamation in their 1966 report on the Jefferson-Whitehall unit concerning the Reichle dam project. The conveyance efficiency of 60 percent is used herein for analytical purposes as a reasonable and useful assumption in estimating irrigation depletions; however, the reader must recognize that actual delivery system efficiencies have not been measured and in all probability range widely from 60 percent.

Calculating the Irrigation Diversion Requirement

Once the data described in the preceding sections had been collected, the irrigation diversion requirement could be calculated using the following formula:

$$IDR = \frac{(PET) - (EP)\ A}{(FE)\ (CE)}$$

where:

IDR = Irrigation diversion requirement in acre-feet
PET = Potential crop evapotranspiration
EP = Effective precipitation in feet
A = Irrigated acres
FE = Farm irrigation efficiency (a fraction)
CE = Conveyance efficiency (also a fraction).

ABOUT MANAGEMENT TECHNIQUES

A major factor that affects crop productivity and crop response to fertilizer and other management techniques is the presence of shallow ground-water conditions in much of the irrigated land area. Experiments in improvement of hay production in the upper Big Hole River basin near Wisdom (Klages and Bowman 1963) showed that:

1) the presence of shallow ground-water conditions (within 24 inches of the land surface) greatly reduces the effectiveness of fertilizer applications. The lack of root zone aeration greatly inhibits crop growth regardless of fertilization practices.

2) fertilizer applications are not profitable unless grasses and clovers with a high yield potential are used in place of native grass.

3) high-yield plants such as Timothy grass, brome grass, and alsike clover do not tolerate shallow ground-water conditions or continuous flood irrigation applications and are killed by continuous flood irrigation.

The presence of shallow ground-water conditions has an adverse effect on the existing irrigated crop productivity of the native grass-sedge mixture, as well as on potential improvements such as high-yield hay and fertilizer applications. The presence of shallow ground water in the root zone of the native grass-sedge mixture results in low yields under existing irrigation management practices.

The areas of shallow ground-water conditions may be divided into three categories. Available information is not presently adequate to determine the relative amounts of land in these three categories subject to shallow ground-water conditions in the Big Hole basin. The first category consists of low alluvial river bottom lands that are subject to shallow ground-water conditions in a state of nature without irrigation. Installation of field drains and drain laterals would be necessary to alleviate shallow ground-water conditions in first-category lands. In most irrigated areas, efficient irrigation water application would probably control the water table without the use of artificial drainage.

The second category of shallow ground-water conditions consists of naturally subirrigated lands where seasonal ground-water levels seldom rise into the crop root zones under natural conditions. Continuous flood irrigation applications to the naturally subirrigated lands cause the water table to rise into the crop root zone. Shallow ground-water conditions could probably be controlled in the subirrigated areas by careful management of irrigation water application and reduction of irrigation applications so that no excess water is applied.

The third category of land experiencing shallow ground-water conditions consists of lands that would not normally experience shallow ground-water conditions in a state of nature. Continuous flood irrigation practices cause shallow ground-water conditions which persist only as long as irrigation continues and abate rapidly when irrigation ceases. Shallow ground-water conditions in third-category areas can be eliminated by management of irrigation water applications.

It is important to recognize the significance of irrigation-caused shallow ground water when considering the demand for increased water use. The provision of storage to control and provide more irrigation water supply will not be an adequate solution to increase crop productivity unless other concurrent measures are taken to manage the efficiency of irrigation water application and to control the water table.

The demand for additional irrigation uses of water from the Big Hole River is influenced by cost factors, a short growing season, and shallow ground-water conditions. Research near Wisdom (Klages and Bowman 1963) indicates that with proper management of irrigation water application, careful selection of crop types, and use of nitrogen and phosphate fertilizers, the productivity of the high mountain meadows in the upper Big Hole River basin may be increased to as much as 4 tons per acre. The present productivity indicated by the results of the DNRC questionnaire is shown on table 14 for locations within the basin.

TABLE 14: Representative hay yields indicated by questionnaire response for the Big Hole River basin.

Location	Acres	Yield (Tons)	Average Yield (Tons/Acre)
Wisdom	7,080	7,080	1.00
Wise River	13,447	14,967	1.11
Divide	1,005	2,185	2.17
Melrose	3,941	9,589	2.43
Glen	4,454	12,348	2.77
Twin Bridges	12,024	27,617	2.30
TOTAL	41,951	73,786	1.96

ABOUT THE COST OF NEW IRRIGATION

Although considerable potential exists to increase irrigation water use, whether the resultant increase in productivity will pay for the cost of the increased water use and thus stimulate demand is an unanswered question. The profitability of increased water use depends on three basic factors:

1) the gross returns to the farm enterprise with the increased water use;

2) the variable costs of the farm operation for labor, equipment, seed, fuel, fertilizer, and other yearly operating costs; and

3) the fixed costs of the farm operation for taxes, insurance, improvements, irrigation water, irrigation equipment, interest on capital investment, and other fixed costs.

A number of studies have attempted to develop models of farm enterprise costs to be used to determine production costs for various crops. The models must use a number of assumptions regarding the size of the farm or ranch and every other item in the budget for fixed and variable costs. Basic assumptions regarding the value of assets (market value or acquisition costs), level of insurance expenses, overall machine capacity, and value of farm labor and capital contributed by the farm or ranch owner all must be averaged or generalized for the models.

In reality, costs differ widely from ranch to ranch due to geographic location, size, soil type, type and condition of machinery, farming methods, general organization and management, weed and insect problems, and other factors. Therefore, use of generalized cost-benefit data may be very misleading in evaluating the feasibility of specific projects, especially small tributary storage projects serving a limited number of local ranches or farms. Costs will have to be evaluated on a project-by-project basis to determine the final relationship between costs and existing demands for increased use of the Big Hole River water supply for irrigation.

An example of generalized cost-benefit data for irrigated alfalfa in the lower basin is shown on table 15. The data on table

15 were developed by the Montana Cooperative Extension Service, Bozeman, in March and April 1978. The data are for a new irrigation system and assume that:

1) alfalfa hay would be grown on an eight-year rotation schedule;
2) yields would be 3 tons per acre for flood irrigation and 3.5 tons per acre for sprinkler irrigation;
3) irrigation diversions would be 2.25 acre-feet per acre for flood systems and 1.75 acre-feet per acre for sprinkler irrigation; and
4) hay would be sold as a cash crop for $50 per ton.

The assumed diversion requirements are substantially lower than calculated diversion requirements and the assumed yields may be somewhat higher than what they actually are. The difference between the Cooperative Extension Service data and the calculated data herein (as based on the 66 questionnaires) does not mean that either set of data is unrealistic, but serves to emphasize the importance of farm management, irrigation efficiency, and other factors in influencing farm enterprise returns. The net income per acre gives some indication of the farm's repayment ability for irrigation water. It should also be noted that these data are not up to date.

TABLE 15: Costs and revenue per acre for irrigated alfalfa.

COSTS		
Variable Costs	Flood	Wheel Line
Fertilizer	$ 16.75	$ 16.75
Irrigation labor	7.27	7.27
Stand establishment	1.55	1.55
Tearing out alfalfa	5.19	5.19
Machinery (fuel, oil and repairs)	10.21	10.21
Pickup	2.70	2.70
Miscellaneous expense	7.06	7.06
Interest on operating capital (9 1/4%)	1.01	1.01
Machinery labor	7.53	7.53
Sprinkler system (wheel line) (electric and maintenance)	7.00	16.70
Total variable costs	$66.27	$75.97
Fixed Costs		
Pump and pipe facilities	13.99	
Pump and pipe facilities and sprinkler system		30.76
Taxes and insurance on land and improvement	7.19	7.19
Buildings	2.43	2.43
Machinery ownership	20.63	20.63
Interest on land (7%)	28.00	28.00
Total fixed costs	72.24	89.01
Total costs	$138.51	$164.98
REVENUE		
Revenue per acre (3 tons x $50)	150.00	
(3.5 tons x $50)		175.00
Less: fixed and variable costs/acre	-138.51	-164.98
Net Income/Acre	$ 11.49	$ 10.02

SOURCE: Montana Cooperative Extension Service (1978).

REFERENCES

American Society of Civil Engineers, 1973. Consumptive Use of Water and Irrigation Water Requirements, 215 pp.

Frost, K.E. and Schwalen, H.C., 1955. Sprinkler Evaporation Losses: Agricultural Engineering, pp. 526-528.

Hanks, R.J., 1974. Model for Predicting Plant Yield as Influenced by Water Use: Agronomy Journal, Vol. 66, pp. 660-665.

Hart, William E. and Reynolds, William M., 1965. Analytical Design of Sprinkler Systems: Transactions of the American Society of Agricultural Engineering.

Klages, M.G., and Bowman, C.C., 1963. Experiments in Mountain Meadow Improvement in the Big Hole Valley: Montana Agricultural Experiment Station, Bozeman, Montana.

Montana Cooperative Extension Service, 1978. Bozeman, Montana.

National Oceanic and Atmospheric Administration (NOAA), 1978. Climatological Data: National Climatic Center, Asheville, N.C.

Soil Conservation Service, 1970. Bozeman, Montana.

Soil Conservation Service, 1974. Irrigation Guide for Montana: Bozeman, Montana.

Sprinkler Irrigation Association, 1975. Sprinkler Irrigation: Fourth Edition, Silver Spring, Maryland, 615 pp.

U.S. Department of Agriculture, 1967 (rev. September, 1970). Irrigation Water Requirements: Soil Conservation Service, Engineering Division, U.S. Government Printing Office, Washington, D.C.

3. INSTREAM FLOW REQUIREMENTS

INTRODUCTION

Studies by the Department of Fish, Wildlife and Parks (DFWP)* have determined instream flow requirements for the Big Hole River for three separate reaches (DFWP 1979). Reach #1 extends about 51 miles from the mouth of the river to the site of the old Divide Dam in section 11, T.1S., R.10W. and is the reach of the river given blue-ribbon status in 1959. Reach #2 extends from the old Divide Dam to the mouth of Pintlar Creek and reach #3 extends from Pintlar Creek to the headwaters of the river.

The instream flow requirements for reach #3 are the smallest; flow requirements for reaches #2 and #1 progressively increase. This report relates all water supply analysis and water demand analysis to instream flows for reach #1. The evaluations herein proceed on the general assumption that the delivery of sufficient instream flows from the upper basin to satisfy instream requirements in reach #1 would also satisfy instream requirements in reaches #2 and #3. This assumption is valid in most cases, although localized instream shortages would exist. All instream flow requirements discussed in this section are for reach #1.

---

* In 1979 the Department of Fish and Game was renamed the Department of Fish, Wildlife and Parks.

METHODOLOGY FOR INSTREAM FLOWS

Instream flow requirements for high-flow periods were determined by the dominant discharge channel morphology concept (DFWP 1979). The theory of the high-flow methodology is that the establishment and maintenance of any particular channel form is dependent upon the annual flood characteristics of the river. In this concept, the high spring flows determine the shape of the channel. The flushing action of high flows is of particular significance in removing deposited sediments and maintaining suitable gravel substrate conditions for aquatic insect production and fish spawning and incubation. Reduction of high spring flows to a level where bedload and sediment transportation is impaired would significantly alter the suitability of the gravel substrate to support aquatic populations.

Substantial evidence is presented that channel form and configuration are controlled by bankfull discharge (Leopold et al. 1964; U.S. Bureau of Reclamation 1973; and Emmett 1975). Bankfull discharge is the flow that occurs when water just begins to overflow the active river floodplain. A period of duration of 24 hours is tentatively selected (DFWP 1979) as the minimum time necessary for the bankfull discharge to provide the channel formation processes. Bankfull discharge tends to have a recurrence interval of 1.5 years (Emmett 1975 and Leopold et al. 1964) and this flow volume can be easily determined if the stream is gaged.

Instream flow requirements for low-flow periods are determined by the wetted-perimeter method. The low-flow methods use field survey data from representative channel cross sections to relate discharge to wetted perimeter. Aquatic habitat potential is a function of wetted perimeter in the channel where wetted perimeter is the distance along the bottom and sides of a channel cross section in contact with water. Comparisons of fish population data and flow data by the DFWP (1979) show that two inflection points which usually occur on plots of wetted perimeter versus flow relate well to flows needed to maintain a low and a high level of aquatic habitat potential.

Field data are collected at representative cross sections for two to three stages of flow within a designated stream reach. Average wetted perimeters are determined for each stream reach. The relationship between flow and wetted perimeters obtained by the measurements is used to determine the flows for the low and the high levels of aquatic habitat potential. Long-term fish population data, where available, are used in conjunction with flow records to verify the accuracy of the wetted-perimeter method for deriving the instream flow requirements.

Table 16 shows the low-level and high-level instream flow requirements computed for the Big Hole River. Again, statistics show that bankfull flows occur 67 out of 100 years. This gives bankfull events a recurrence frequency of 1.5 years.

TABLE 16: Low-level and high-level instream flow requirements for the Big Hole River.

Month	Low-Level Instream Flow Requirement (in cfs)	High-Level Instream Flow Requirement (in cfs)
January	300	600
February	300	600
March	300	600
April	699	821
May	2,194	2,194
June	2,696	2,696
July	659	814
August	300	600
September	300	600
October	300	600
November	300	600
December	300	600

AQUATIC HABITAT POTENTIAL

Aquatic habitat quality, fish populations, and fish size are directly related to instream flow. The relationship between flow regimes, habitat conditions, and fish populations is rated using levels of habitat potential. The levels used range from optimum habitat conditions to base levels for survival. The amount of protection provided to the aquatic resource, that is to say, the level of habitat maintenance desired, is defined in the following paragraphs which are quoted verbatim from the 1979 DFWP report:

1. Optimum Level of Aquatic Habitat Potential--The discharge regime which allows for a maximum expression of the carrying capacity of aquatic populations consistent with the physical constraints of channel configuration, cover and general productivity of the drainage. In some cases, this would require a return to a pristine flow regime or one as it existed prior to significant water depletions. In others, this level of habitat maintenance would imply securing the present flow regime with little or no future depletions.

2. High Level of Aquatic Habitat Potential--That flow regime which will consistently produce abundant, healthy and thriving aquatic populations. In the case of game fish species, these flows would produce abundant game fish populations capable of sustaining a good to excellent sport fishery for the size of stream involved. For rare, threatened or endangered species, flows to accomplish the high level of aquatic habitat maintenance would: 1) provide for high population levels to ensure the continued

existence of that species or, 2) provide for flow levels above that which would adversely affect the species.

3. Low Level of Aquatic Habitat Potential--Flows to accomplish the low level of aquatic habitat maintenance would provide for only a low population abundance of the species present. In the case of game fish species, a poor sport fishery could still be provided. For rare, threatened or endangered species, their populations would exist at low or marginal levels. In some cases, this flow level would not be sufficient to maintain certain species.

4. Critical Level of Aquatic Habitat Potential--A flow regime which would eliminate many of the aquatic species. Only the more adaptable and resistant species would survive at levels capable of recovering if more desirable flows were provided. Rare, threatened and endangered species would probably be eliminated. A sport fishery could not be provided with these flows.

Population estimates for brown trout and wild rainbow trout have been developed from a 22,500-foot section of reach #1 near Melrose by a number of investigators. The population estimate data are summarized by DFWP (1979) and primary data references are provided. The conclusions presented by DFWP are that populations for both species fluctuate in response to available instream flows and that wild rainbow trout populations were severely affected by depletions of instream flow during the period of record.

REFERENCES

Montana Department of Fish and Game, 1979. Instream flow evaluation for selected streams in the Upper Missouri River basin.

Leopold, L.B., Wolman, G.M. and Miller, J.P., 1964. Fluvial process in geomorphology: W.H. Freeman and Co., San Francisco. 522 pp.

U.S. Bureau of Reclamation, 1973. Design of small dams: U.S. Government Printing Office, Washington, D.C.

Emmett, W.W., 1975. The channels and waters of the Upper Salmon River area, Idaho: U.S. Geol. Survey professional paper 870-A. 96 pp.

4. DEMANDS AND SHORTAGES

IRRIGATION

Table 17 compares average monthly irrigation diversion requirements for full irrigation supplies in the upper basin under existing conditions and practices to average monthly water supplies based on 55 years of record.

The average monthly flow fails to satisfy average irrigation diversion requirements in the month of August even without consideration of other water uses. The 18,037-acre-foot shortage in August (table 17) is based on average values. In above average years the shortage will be less and in below average flow years the shortage will be greater and may extend into other months.

TABLE 17: Monthly irrigation diversion requirements compared to average monthly flows in the upper basin (acre-feet/month).

Month	Diversion Requirement	Average Flow	Average Shortages
May	21,150	284,371	0
June	43,856	289,558	0
July	101,087	151,331	0
August	71,849	53,812	-18,037
September	27,060	31,803	0

The data on table 17 show that shortages in irrigation water supplies exist regardless of the type of diversion structures used. Information shown on table 18, based on the questionnaire data, indicates that current irrigation operation practices under existing short supply conditions deliver only 6.95 inches of effective irrigation water to crop plants. The 6.95 inches of irrigation combined with 4.60 inches of effective precipitation result in a 3.20-inch shortage in satisfying the crop requirement. The 3.20-inch shortage on 112,085 acres with prevalent irrigation efficiencies equals an average estimated irrigation diversion shortage of about 99,631 acre-feet per year.

TABLE 18: Estimated irrigation water applications in the Big Hole River basin for existing water supplies, levels of irrigation, and crop patterns (in inches).

	Upper Basin (grass)	Lower Basin (alfalfa)
Potential Evapotranspiration	13.12	21.40
Annual Irrigation Application	-6.95	-19.21
Effective Precipitation	-4.60	-4.58
Initial Soil Moisture Deficit	1.63	2.39
Leaching Requirement	0	0
ANNUAL IRRIGATION SHORTAGE	3.20	0

The large discrepancy between the 18,037 acre-foot average shortage indicated by average monthly flow data and the 99,631-acre-foot irrigation diversion shortage indicated by analysis of current irrigation practices reflects the physical distribution of water supplies in the upper Big Hole basin. About 70 percent of the upper basin irrigators divert from tributaries of the Big Hole River. Flows adequate to support irrigation diversions from the tributaries occur mostly in May and June, during peak snowpack melting and run-off. Flows in the tributaries decrease substantially or cease by late July and will irrigate only a small portion of the upper basin lands.

In contrast, flows in the mainstem river, although also reduced, are still adequate to support a fair amount of irrigation diversion compared to the tributaries. The mainstem, however, is used by only 30 percent of the irrigators.

MUNICIPAL

The present requirement of 10,577 acre-feet per year for municipal water supply means an average monthly requirement of about 881 acre-feet. The Butte Water Company requires an additional 1,120 acre-feet per month for a total of 2,001 acre-feet per month. The 2,001 acre-feet per month requirement is increased to 2,883 acre-feet per month in June, July, and August to bring the total diversion requirement in the upper basin for municipal use to 26,658 acre-feet per year. The demand of 26,658 acre-feet for municipal supply is a good estimate of maximum foreseeable demand for municipal water supplies if all communities in the Big Hole River basin were to convert solely to surface water supplies for potable water. This is a relatively small requirement compared to other uses and, as discussed herein, probably less than 50 percent of the 26,658 acre-feet is used under existing conditions. Other municipal requirements in the lower basin for 40 people at Glen would total 627 acre-feet per year under the above assumptions.

An additional potential demand is presented by the Butte Water Company. The maximum existing pumping plant capacity for the Butte Water Company diversion is 12 million gallons per day (mgd) (Patterson 1980) and the pipeline capacity available for possible expansion is 25 mgd. Maximum potential municipal and other demands for consumptive use are estimated to be 42,000 acre-feet per year for the purpose of this analysis.

INSTREAM FLOWS

Management of the Big Hole River to satisfy water rights for irrigation and municipal use puts the burden of shortages on instream uses.

Two conditions are examined to determine shortages. In the first condition, shown in table 19, it is assumed that present irrigation practices are adhered to, including annual shortages in mid-July, on 112,085 acres in the upper Big Hole River basin. Shortages are determined for both low and high levels of aquatic habitat potential and municipal uses are maintained at a constant

TABLE 19. Current irrigation practices in the upper Big Hole River basin, as calculated at the Melrose gaging station.

MONTH	DEMANDS (ACRE-FEET) IRRIG.	INSTM.	MUNIC.	TOTAL	SUPPLY (ACRE-FT)	BALANCE (ACRE-FT)	BALANCE (cfs)
LOW LEVEL OF AQUATIC HABITAT POTENTIAL							
January	0	18,442	2,001	20,443	21,555	1,112	18
February	0	16,657	2,001	18,658	20,447	1,789	32
March	0	18,442	2,001	20,443	27,849	7,406	120
April	0	41,584	2,001	43,585	91,821	48,236	811
May	71,849	134,896	2,001	208,746	284,371	75,625	1,230
June	43,856	160,442	2,883	207,181	289,558	82,377	1,384
July	67,374	40,512	2,883	110,769	151,331	40,562	660
August	23,926	18,442	2,883	45,251	53,812	8,561	139
September	9,011	17,847	2,001	28,859	31,803	2,954	50
October	0	18,442	2,001	20,443	31,252	10,809	176
November	0	17,847	2,001	19,848	30,201	10,353	174
December	0	18,442	2,001	20,443	24,591	4,148	67
	216,016	521,995	26,658	764,659	1,058,591	293,932	
HIGH LEVEL OF AQUATIC HABITAT POTENTIAL							
January	0	36,884	2,001	38,885	21,555	-17,330	-282
February	0	33,314	2,001	35,315	20,447	-14,868	-268
March	0	36,884	2,001	38,885	27,849	-11,036	-179
April	0	50,507	2,001	52,508	91,821	39,313	661
May	71,849	134,896	2,001	208,746	284,371	75,625	1,230
June	43,856	160,442	2,883	207,181	289,558	82,377	1,384
July	67,374	50,031	2,883	120,288	151,331	31,043	505
August	23,926	36,884	2,883	63,693	53,812	-9,881	-161
September	9,011	35,894	2,001	46,706	31,803	-14,903	-250
October	0	36,884	2,001	38,885	31,252	-7,633	-124
November	0	35,694	2,001	37,695	30,201	-7,494	-126
December	0	36,884	2,001	38,885	24,591	-14,294	-232
	216,016	684,998	26,658	927,672	1,058,591	130,919	

rate. The conditions approximate the existing situation in the upper basin within the qualifications and assumptions set forth in chapter II of the main report.

In the second condition, shown in table 20, a full irrigation water supply is assumed for the 112,085 acres of land currently irrigated in the upper basin. The negative numbers in the balance columns of tables 19 and 20 represent shortages. It is necessary to remember that the shortages shown in the balance columns are for overall water supplies and do not necessarily reflect water distribution.

The demand-supply balance on table 19 shows that under present irrigation practices, which include midseason shortages, the low level aquatic habitat flow requirements are satisfied in average or above average years. The demand-supply balance data in table 20 show the true shortages that currently exist for the combined uses if a full supply of water is to be provided to irrigation.

Competitive uses for water supplies in the upper basin of the Big Hole River, as shown by tables 19 and 20, result in shortages beginning in the month of July in an average year. The estimated shortages due to competitive uses in the months of July, August, and September total 63,426 acre-feet (table 20) in an average year assuming a high level of aquatic habitat potential is desired.

TABLE 20. Provision of a full water supply to presently irrigated lands using existing irrigation practices in the upper Big Hole River basin.

MONTH	LOW LEVEL OF AQUATIC HABITAT POTENTIAL DEMANDS (ACRE-FEET) IRRIG.	INSTM.	MUNIC.	TOTAL	SUPPLY (ACRE-FEET)	BALANCE (ACRE-FT)	BALANCE (cfs)
January	0	18,442	2,001	20,443	21,555	1,112	18
February	0	16,657	2,001	18,658	20,447	1,789	32
March	0	18,442	2,001	20,443	27,849	7,406	120
April	0	41,584	2,001	43,585	91,821	48,236	811
May	21,150	134,896	2,001	158,047	284,371	126,324	2,054
June	43,856	160,442	2,883	207,181	289,558	82,377	1,384
July	101,087	40,512	2,883	144,482	151,331	6,849	111
August	71,849	18,442	2,883	93,174	53,812	-39,362	-640
September	27,060	17,847	2,001	46,908	31,803	-15,105	-254
October	0	18,442	2,001	20,443	31,252	10,809	176
November	0	17,847	2,001	19,848	30,201	10,353	174
December	0	18,442	2,001	20,443	24,591	4,148	67
	265,002	521,995	26,658	813,655	1,058,591	244,936	
	HIGH LEVEL AQUATIC HABITAT POTENTIAL						
January	0	36,884	2,001	38,885	21,555	-17,330	-282
February	0	33,314	2,001	35,315	20,447	-14,868	-268
March	0	36,884	2,001	38,885	27,849	-11,036	-179
April	0	50,507	2,001	52,508	91,821	39,313	661
May	21,150	134,896	2,001	158,047	284,371	126,324	2,054
June	43,856	160,442	2,883	207,181	289,558	82,377	1,384
July	101,087	50,031	2,883	154,001	151,331	-2,670	-43
August	71,849	36,884	2,883	111,616	53,812	-57,804	-940
September	27,060	35,694	2,001	64,755	31,803	-32,952	-554
October	0	36,884	2,001	38,885	31,252	-7,633	-124
November	0	35,694	2,001	37,695	30,201	-7,494	-126
December	0	36,884	2,001	38,885	24,591	-14,294	-232
	265,002	684,998	26,658	976,658	1,058,591	81,933	

Shortages due to competitive uses are presented for the lower basin of the Big Hole River on tables 21 and 22. The conditions assumed for the tables are essentially those used for tables 19 and 20. Existing conditions assume provision of a partial irrigation water supply to upper basin lands being cropped for grass (112,085 acres) and provision of a full irrigation water supply to 21,769 acres of lower basin lands being cropped for alfalfa. The conditions on table 20 make the same assumptions except that a full irrigation water supply is assumed for both the upper basin grass crops and the lower basin alfalfa crops.

Estimates of supply-demand balances on table 21 show that shortages in an average year due to competitive uses begin in the lower basin area in August for both low-level and high-level instream use assumptions, although irrigation practices assumed for existing conditions provide only partial irrigation supplies in the upper basin. The shortages on table 21 show that under current management conditions, including provision of only partial irrigation supplies in the upper basin, shortages for all use requirements occur in the lower basin area during average and below average flow years.

Current management practices include satisfying irrigation diversion requirements prior to satisfying other use requirements, including instream flows. Under current management practices, the

TABLE 21. Current partial irrigation practices in the Big Hole River basin as calculated for the river at the confluence based on existing irrigated acreages and crops.

MONTH	DEMANDS (ACRE-FEET)				SUPPLY	BALANCE	BALANCE
	IRRIG.	INSTM.	MUNIC.	TOTAL	(ACRE-FEET)	(ACRE-FT)	(cfs)
LOW LEVEL OF AQUATIC HABITAT POTENTIAL							
January	0	18,442	2,001	20,443	23,032	2,589	42
February	0	16,657	2,001	18,658	21,642	2,984	54
March	0	18,442	2,001	20,443	29,425	8,982	146
April	0	41,584	2,001	43,585	94,382	50,797	854
May	98,577	134,896	2,001	235,474	297,222	61,748	1,004
June	62,481	160,442	2,883	225,806	313,892	88,026	1,480
July	102,749	40,512	2,883	146,144	164,086	17,942	292
August	52,649	18,442	2,883	73,974	61,192	-12,782	-208
September	15,723	17,847	2,001	35,571	34,379	- 1,192	-20
October	0	18,442	2,001	20,443	34,660	14,217	231
November	0	17,847	2,001	19,848	32,682	12,834	216
December	0	18,442	2,001	20,443	25,778	5,335	87
	332,179	521,995	26,658	880,832	1,132,372	251,540	
HIGH LEVEL AQUATIC HABITAT POTENTIAL							
January	0	36,884	2,001	38,885	23,032	-15,853	-258
February	0	33,314	2,001	35,315	21,642	-13,673	-246
March	0	36,884	2,001	38,885	29,425	-9,460	-154
April	0	50,507	2,001	52,508	94,382	41,874	704
May	98,577	134,896	2,001	235,474	297,222	61,748	1,004
June	62,481	160,442	2,883	225,806	313,892	88,086	1,480
July	102,749	50,031	2,883	155,663	164,086	8,423	137
August	52,649	36,884	2,883	92,416	61,192	-31,224	-508
September	15,723	35,694	2,001	53,418	34,379	-19,039	-1,475
October	0	36,884	2,001	38,885	34,660	-4,225	-69
November	0	35,694	2,001	37,695	32,682	-5,013	-84
December	0	36,884	2,001	38,885	25,778	-13,107	-213
	332,179	684,998	26,658	1,043,835	1,132,372	88,537	

August and September shortages shown on table 21 are suffered primarily by instream uses. Moreover, as shown by comparing the supply-demand balances on table 19 to those on table 21, it is clear that the largest impact of the shortages on instream use is in the lower basin area (table 22) and that the impacts on instream use in the lower basin are most severe in the critical use period of August and September. The foregoing conclusions are substantiated by the historic dewatering of river reaches in the lower basin in years of below average flow.

TABLE 22: Comparison of estimated average monthly shortages for the lower and upper basins under current management conditions, assuming maintenance of a high level of aquatic habitat potential.

Month	Upper Basin Shortages* (cfs)	Lower Basin Shortages** (cfs)	Differences in Shortages*** (cfs)
January	-282	-258	-24
February	-268	-246	-22
March	-179	-154	-25
April	0	0	0
May	0	0	0
June	0	0	0
July	0	0	0
August	-161	-508	347
September	-250	-1,475	1,225
October	-124	-69	-55
November	-126	-84	-42
December	-232	-213	-19

* Balance from table 19
** Balance from table 21
*** Upper basin shortage minus lower basin shortage

Competitive uses result in shortages beginning in July for both low and high levels of aquatic habitat potential management. The largest shortages occur in the lower basin during the competitive use months of July, August, and September. The estimated shortage in total average water supply for the period July through September is 141,525 acre-feet in a year of average flow. The total estimated shortage will be less in a year of above average flow and more in a year of below average flow. The shortages in water supply do not reflect shortages experienced by different uses at different times and locations.

ESTIMATED SUPPLIES AND SHORTAGES

Comparing the Big Hole River's average monthly water supplies to average monthly demands basin wide provides an estimate of supplies and shortages.

The total potential demands for irrigation, instream, and other uses of water for the Big Hole River basin as a whole are shown on table 23 for five levels of development. Development levels are defined in chapter II of the main report. Development level 1 corresponds to existing conditions. Development level 2 corresponds to existing levels of irrigated land development, but with a full supply of water compared to currently existing short water supplies

TABLE 23. Comparison of overall average annual water supply of the Big Hole River basin to the total potential demands for all uses in an average year.

DEVELOPMENT LEVEL	IRRIGATION DEVELOPMENT LEVEL						INSTREAM FLOW		MUNICIPAL AND OTHER	TOTAL POTENTIAL DEMAND	AVERAGE ANNUAL SUPPLY	SUPPLY DEMAND BALANCE	REMARKS
	IRRIGATED ACRES	CROP TYPE		IRRIGATION METHOD	SUPPLY ADEQUACY	IRRIGATION DIVERSION	LOW LEVEL	HIGH LEVEL					
		LOWER BASIN	UPPER BASIN										
1	133,854	ALFALFA	GRASS HAY	FLOOD[1]	PARTIAL	332,178	521,995	--	26,658	880,831	1,132,372	251,541	EXISTING CONDITIONS
1a	133,854	ALFALFA	GRASS HAY	FLOOD[1]	PARTIAL	332,178	--	684,998	26,658	1,043,834	1,132,372	88,538	EXISTING CONDITIONS
2	133,854	ALFALFA	GRASS HAY	FLOOD[1]	FULL	381,164	521,995	--	26,658	920,541	1,132,372	201,831	EXISTING DEMANDS
2a	133,854	ALFALFA	GRASS HAY	FLOOD[1]	FULL	381,164	--	684,998	26,658	1,093,544	1,132,372	38,828	EXISTING DEMANDS
3	133,854	ALFALFA	GRASS HAY	MIXED[2]	FULL	347,975	521,995	--	26,658	896,628	1,132,372	235,744	ALL SPRINKLER IN LOWER BASIN; ALL FLOOD IN UPPER BASI
3a	133,854	ALFALFA	GRASS HAY	MIXED[2]	FULL	347,975	--	684,998	26,658	1,059,631	1,132,372	72,741	ALL SPRINKLER IN LOWER BASIN; ALL FLOOD IN UPPER BASI
4	199,024	ALFALFA	MIXED[3]	MIXED[2]	FULL	541,732	521,995	--	26,658	1,090,385	1,132,372	41,987	SEE FOOTNOTE 4
4a	199,024	ALFALFA	MIXED[3]	MIXED[2]	FULL	541,732	--	684,998	26,658	1,253,388	1,132,372	-121,016	SEE FOOTNOTE 4; NOTICE DEMAND EXCEEDS SUPPLY
5	199,024	ALFALFA	MIXED[3]	MIXED[2]	FULL	541,732	521,995	--	42,000	1,105,727	1,132,372	26,645	SEE FOOTNOTE 5
5a	199,024	ALFALFA	MIXED[3]	MIXED[2]	FULL	541,732	--	684,998	42,000	1,268,730	1,132,372	-136,358	SEE FOOTNOTE 5, NOTICE DEMAND EXCEEDS SUPPLY

FOOTNOTES:

1/ Flood irrigation assumes 60% conveyance efficiency and 50% farm efficiency for 30% overall efficiency.

2/ Mixed irrigation assumes a combination of flood and sprinkler irrigation. Flood irrigation efficiency is shown in Footnote 1. Sprinkler irrigation efficiency assumes 60% conveyance efficiency and 70% farm efficiency for 42% overall efficiency.

3/ Mixed crops for upper basin assumed grass hay on 112,085 presently irrigated acres and alfalfa on 59,258 new acres. Mixed crops for lower basin assume 27,681 acres alfalfa consisting of 21,769 presently irrigated acres and 5,912 new acres.

4/ Upper basin irrigation consists of 112,085 acres flood and 59,258 acres sprinkler. Lower basin irrigation consists of 21,769 acres flood and 5,912 acres sprinkler.

5/ Irrigation methods are same as Footnote 4. Municipal demands are increased to meet full 25 mgd capacity of Butte Water Co. pipeline and 761 acre-feet per year other uses.

tolerated at development level 1. Other advanced levels of increased water use are represented by development levels 3, 4, and 5.

The information on table 23 is particularly useful in comparing the overall average annual water supply of the Big Hole River basin to the total potential demands for all uses in an average year. As noted above, the supply-demand balance does not represent shortages or excess supplies experienced by the different uses. The supply-demand balance merely shows the potential for water supplies generated in the overall basin to satisfy total potential demands without regard to location and timing of supplies and demands. Negative numbers in the supply-demand balance column on table 23 indicate that total potential demands in an average year exceed the sum total of average annual water supply generated by the Big Hole River basin.

Figure 6 uses the ten-year period with the lowest average flow to show the calculated spills and shortages upstream from Melrose from a hypothetical dam in the Big Hole basin. The figure assumes present irrigation practices, low-level aquatic habitat, and 48,679 acre-feet of storage. It also assumes 100 percent delivery of stored water to acres of use with no instream losses. Figure 7 plots hypothetical storage size against water volume for reservoir

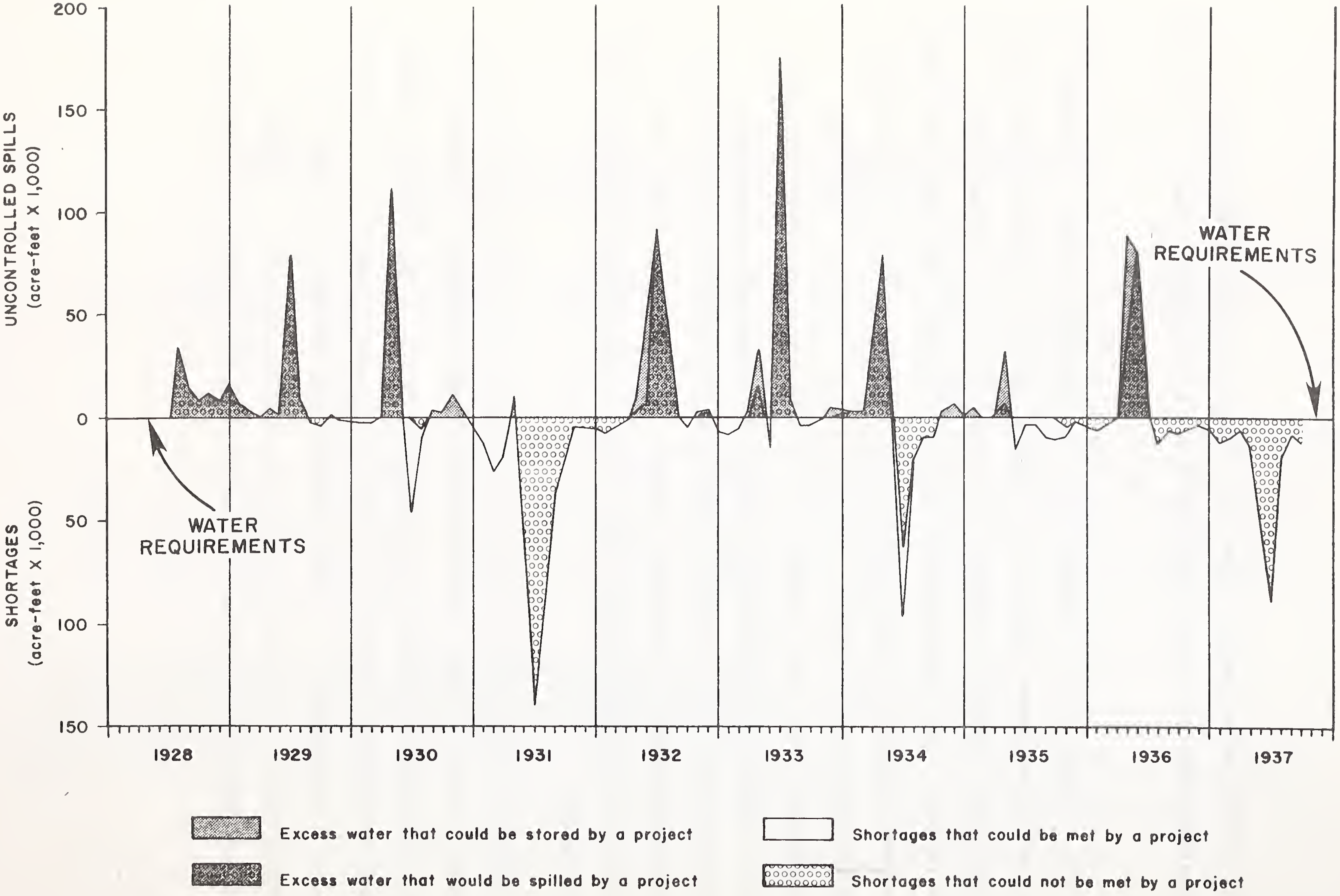
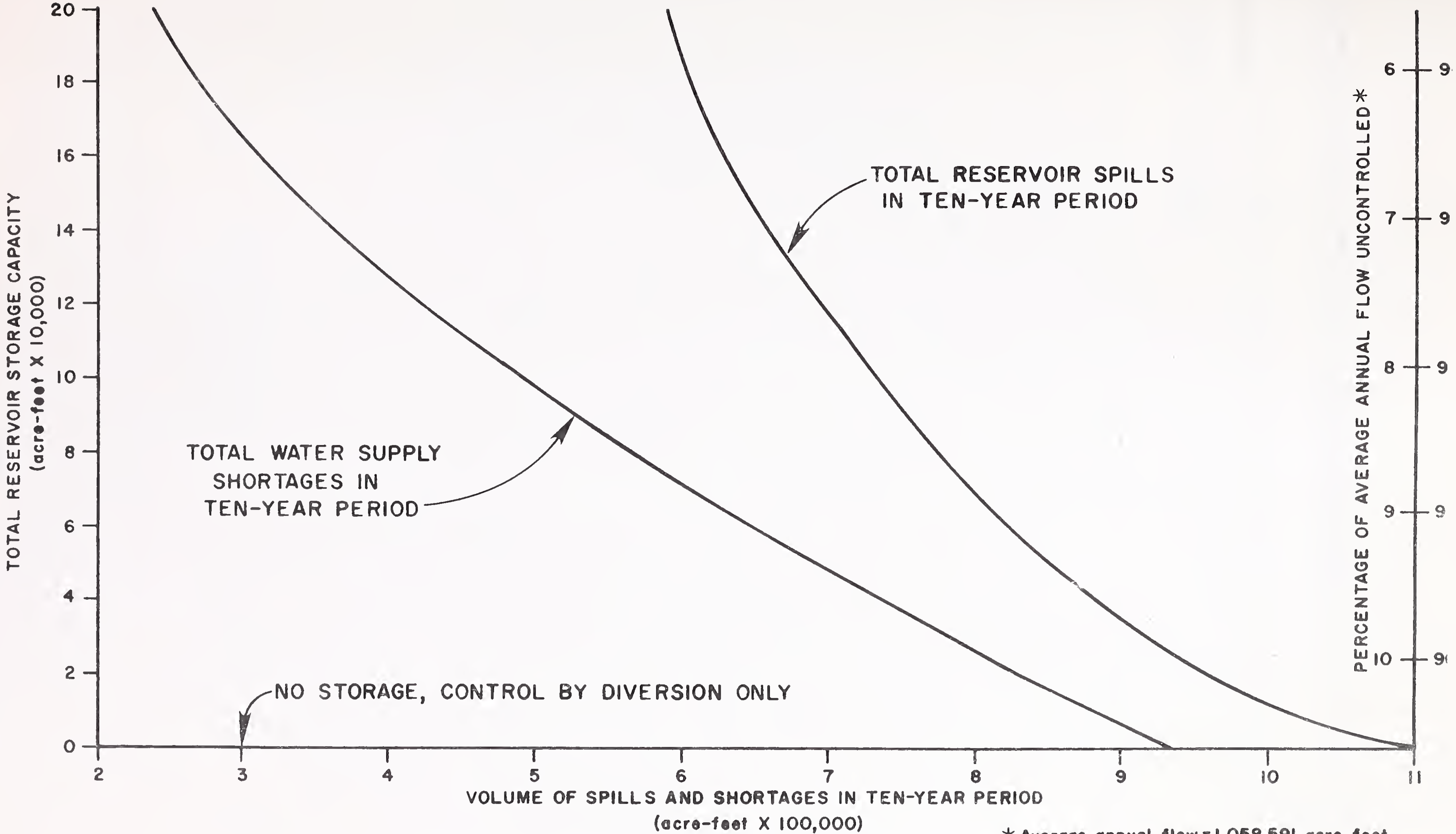


FIGURE 6. Hypothetical spills and shortages in the Big Hole basin.



* Average annual flow = 1,058,591 acre-feet

FIGURE 7. Storage versus spills and shortages for the driest 10 years of record above Melrose assuming an existing level of irrigation practices and a low level of aquatic habitat potential.

spills and total water supply during the ten-year period plotted in figure 6.

REFERENCE

Patterson, M., 1980. Written Communication: Butte Water Co., Butte, Montana.

5. TRAIL CREEK DAM SITES

OVERVIEW

Two sites were investigated on Trail Creek. The upstream site, termed the Thin Man site, is in section 15, T.2S., R.18W. The downstream site is termed Fat Man and is in section 14, T.2S., R.18W. Both sites are located on granitic bedrock in mountain terrain.

The geology of the sites does not present any unusual or difficult problems that affect engineering feasibility. However, materials sources in and around the Trail Creek sites may limit engineering design options to a rockfill structure. The probable lack of a suitable materials source for impervious earthfill near the sites may require use of an artificial core in an earthfill embankment or an artificial membrane in a rockfill embankment. The artificial core or membrane requirement may result in even higher costs than those estimated in this report.

Other factors influencing costs at the Trail Creek sites are road relocation and emergency spillway requirements. Approximately 5.3 miles of state highway will require relocation over rugged mountainous terrain at a total estimated cost of $5.3 million. Road relocation costs will be relatively expensive due to drilling and blasting requirements in most of the road cuts. It is tentatively assumed that a dam on either one of the Trail Creek sites will require an emergency spillway capable of passing a probable maximum flood (PMF), in order to meet recommended safety criteria for a high-hazard dam. The estimated construction costs associated with a PMF spillway are substantially reduced in this report by assuming use of surcharge to contain a PMF rather than use of an emergency spillway.

The average annual water supply to the Fat Man site on Trail Creek is 37,545 acre-feet per year. The estimated PMF peak rate of discharge for the Fat Man site is 95,000 cfs and the PMF volume is 36,000 acre-feet. The topography at the Fat Man site provides the potential to store more than 100,000 acre-feet of water. A dam 176 feet high would store 135,910 acre-feet at the Fat Man site.

The percentage of the long-term average annual water supply that would be regulated for beneficial use (low-level instream requirements and irrigation) during the ten-year critical period of lowest stream flows is shown on table 24 for different reservoir capacities including reservoir capacities that provide carry-over storage in excess of average annual supply.

The maximum irrigated acres shown on table 24 are the maximum acres that can be provided with a full irrigation diversion requirement without any shortages in the driest year. The costs per acre-foot on table 24 assume all costs are born by irrigation with no sharing in costs by other uses such as flood control, recreation, or fish and wildlife enhancement.

An inventory of presently irrigated and irrigable, but not presently irrigated, lands in the Big Hole River basin shows the Fat Man site can serve 26,261 acres of land that are presently irrigated with short water supply and an additional 17,805 acres of irrigable lands not presently irrigated. The combination of shortages on presently irrigated lands and water requirements for new lands would easily exceed the maximum irrigated acres that could be provided a firm annual water supply by the Fat Man site.

TABLE 24: Regulation, irrigated acreage, and costs per acre-foot for reservoir capacities at the Fat Man site.

Reservoir Capacity (acre-feet)	Percent of Average Annual Supply Regulated	Acre-Feet Regulated	Maximum Irrigated Acres	Cost Per Acre-Foot (1980 dollars)
5,000	82.1	30,824	4,455	81
6,000	84.0	31,538	4,455	81
10,000	91.5	34,354	4,455	82
15,000	95.6	35,893	4,455	90
20,000	95.6	35,893	4,455	97
40,000	95.6	35,893	7,363	72
60,000	95.6	35,893	7,363	80
80,000	95.6	35,893	7,363	85
100,000	95.6	35,893	11,462	59

ENGINEERING-GEOLOGIC INVESTIGATIONS

A reconnaissance engineering-geologic field inspection of the two potential dam sites on Trail Creek was conducted on June 16, 1980, by Mike Kaczmarek, chief geologist for Morrison-Maierle, Inc. and Roger Noble, hydrogeologist for the Water Sciences Bureau, Montana Department of Natural Resources and Conservation.

The purpose of the reconnaissance field inspection was to assess the general feasibility of the sites for dam construction from a geologic standpoint and to detect any geologic conditions that might render the sites undesirable in terms of foundation, abutment, or reservoir conditions. The field inspection revealed that the geologic materials and geologic structures of the foundations, abutments, and reservoir areas are suitable for use as dam and reservoir sites and do not present any unusual or unconventional engineering or construction problems.

General Geology

The Fat Man and Thin Man sites are located on granitic rocks of the Idaho batholith. The Idaho batholith is an extensive mass of intrusive granitic rock that occupies most of central Idaho and small portions of western Montana. It is believed the greater part of the main body of the batholith consolidated from magma essentially as a unit or an aggregate of large units. Although numerous geologic structures are present in the rocks flanking the eastern margin of the batholith, geologic structures in the main batholith mass seem to be limited to a few widespread normal faults.

Site geology is similar at both the Fat Man and Thin Man sites. The abutments consist of massive granitoid rock. Road cut exposures along State Route 43 reveal the rocks to be a granite and quartz monzonite. The rock is fresh in the road cuts and is difficult to break with a geologist's pick, a fact indicative of high compressive strength. A few north-northeast trending, nearly vertical dikes of dark diabasic rock, 2 to 3 feet wide, are exposed in the road cuts. Ridge tops in the granite and quartz monzonite are supported by shallow to exposed bedrock, whereas some cuts in the sides of water courses reveal 10 to 15 feet of weathered rock consisting chiefly of granitic sand.

ABUTMENTS

The abutment rocks are cut by three or more joint sets and tend to split into blocky fragments on 2-to-4-foot intervals in the road cuts. Talus blocks are cubical to rectangular. The joints observed in the highway road cuts are distinct, continuous, and very tight, even in the weathered zone. It is probable that the joint openings are less than a few millimeters wide in unweathered rock under normal lithostatic load. The joints do not appear to present a major path of seepage potential and may be satisfactorily treated by shallow surface grouting (blanket grouting) unless deeper fracture zones are discovered by test drilling.

The possibility that permeable fracture zones may be present in the abutments or granitic foundation rocks is evidenced by the presence of several high-angle shear zones observed in road cuts along state Route 43. The shear zones are no wider than a foot and do not exhibit displacement or brecciated, granulated rock. The shear zones are characterized by slabby partings along joints parallel to the shear zones. Weak fabric alignment of dark minerals is parallel to the shear zones in opposition to the weakly gneissic structure in the granitic rocks outside the shear zones. The so-called shear zones may represent late-stage mobilization of magmatic material along zones of stress in the consolidating magma body. Regardless of the origin of the shear zones, they may present potential seepage paths in the foundation and abutment rocks.

FOUNDATION

Shallow foundation materials at the two potential dam sites consist of unconsolidated alluvial sand and gravel. The alluvium consists almost exclusively of granitoid gravels and decomposed granitic sand. The depth of the alluvium is unknown and probably is several tens of feet thick and the alluvial foundation materials rest on granite and quartz monzonite rock.

The alluvial foundation materials on the surface are loose to firm and have an estimated relative density of 50 to 70 percent. Relative density may be greater with increased depth; however, the alluvial materials present a potential zone of differential foundation settlement, high seepage loss, and seepage uplift pressure. The characteristics of the granitic rocks beneath the alluvium are assumed to be similar to those in the abutments.

RESERVOIR AREAS

The reservoir areas of the two potential dam sites are both contained entirely within the granitic rocks of the Idaho batholith. The valley floors in the reservoir areas consist of unconsolidated alluvium as described in the foundation areas. The reservoir areas do not present any potential for significant seepage losses or bank storage. The reservoir banks are stable and do not present landslide hazards or significant rock-fall hazards.

MATERIALS SOURCES

Materials sources in the vicinity of the Fat Man and Thin Man sites are limited to sand and gravel from the unconsolidated alluvium, decomposed sand from weathered granitic bedrocks, small deposits of loose rock talus, and potential quarry sites in the granitic bedrocks.

Potential sand and gravel sources are restricted to the alluvial valley floor of Trail Creek. Almost all of the alluvial deposits are subject to a shallow water table except for a limited area in the NW1/4, section 15, T.2S., R.18W. in the confluence of Trail and Joseph creeks. The alluvial sand and gravel are a good potential source of pervious materials for filters and drains. The suitability of the alluvial sand and gravel for use as compacted embankment material is questionable and would require careful testing.

The high content of granitic gravel fragments may reduce the strength and durability of the gravels for use as compacted fill, outer shell material, or road metal. Much of the granitic gravel is highly weathered and may tend to break down under compaction, loading, or continued exposure to weathering at the land surface. Alluvium derived from weathered granitic terrain tends to produce gap-graded gravels or uniform gravels that do not meet gradation specifications for impervious compacted earth embankments.

The foregoing considerations suggest a strong possibility that the alluvium in the Trail Creek watershed may not be suitable for use in the impervious portions of a zoned, earthfill dam. Other materials in the local vicinity are not a source of impervious fill.

If engineering materials tests confirm these speculations, design engineers may have to confine use of the alluvium as earthfill to homogeneous embankments. Construction of a dam with homogeneous earthfill embankments would require use of impermeable foundation cutoffs, and impermeable embankment cores constructed with concrete or other impervious construction materials. If the alluvium is not suited to zoned, earthfill dam construction, the design engineers may wish to consider alternative dam designs including a rockfill dam using material quarried from the granitic bedrock.

The large percentage of weathered or partially decomposed granitic rock, as well as the considerable mica content in the alluvial sand and gravel may also limit their suitability for use as a source of concrete aggregate. Exhaustive sampling and testing would be required to confirm the properties of the alluvium for different engineering uses. However, the foregoing engineering-geologic considerations are presented herein because they may greatly influence the construction costs at the Trail Creek sites and may ultimately influence the type of dam design most appropriate for the site.

Decomposed granitic sand is present as colluvial fans and residuum on the surface of deeply weathered areas of the batholithic rocks. The average depth of the granitic sands is probably less than 10 to 15 feet. The granitic sands may be a source of pervious material for certain drain applications. The presence of considerable mica and potentially silica-reactive altered feldspars in the granitic sands makes the granitic sands very questionable as a suitable source of concrete sand.

Small rock talus deposits at the bottom of low cliffs may be a source of rock fill for riprap. However, the deposits observed during the limited field inspection on June 16, 1980, were very small and did not contain much material. Moreover, the rounded, weathered aspect of the talus fragments suggests that careful durability tests would be required to determine the suitability of the talus for use as riprap.

The granite and quartz monzonite bedrock below the zone of weathering may be a prime source of rock fill, riprap, road metal, and possibly crushed concrete aggregate. The granitic bedrocks are available in unlimited supply over a wide area near the potential dam sites. Engineering materials testing would be required to determine the suitability of the granitic bedrocks for these uses.

GEOLOGIC SUMMARY

The information obtained by the June 16, 1980, reconnaissance engineering-geologic field inspection shows the Fat Man and Thin Man sites are suitable sites for dam construction. The limited availability of local sources of impervious fill material may limit design concepts to homogeneous embankments with concrete or other impermeable core material or to concepts of rockfill embankments with concrete or other impermeable membrane lining. Use of either of the foregoing design concepts would require the construction of an impermeable foundation cutoff wall keyed into the bedrock foundation below the alluvium. Partial cutoffs would not be satisfactory. Cutoff construction would require dewatering of the unconfined alluvial ground-water system in the vicinity of the construction site. Alternative embankment design concepts may require transportation of earthfill materials to the sites from relatively distant borrow areas. Embankment design concepts may depend on cost comparisons between the use of the local materials for inherently more costly designs, versus importing materials over relatively long distances for use in less costly designs.

Hydrology

Water supply calculations for Trail Creek are based on records from a stream-flow gaging station located on Trail Creek in the SW1/4, section 16, T.2S., R.17W. The average annual discharge based on seven years of record from 1948 to 1951 and 1966 to 1970 is 60,130 acre-feet per year (USGS 1974) for a 71.4-square-mile drainage area. Average annual water supply adjusted to coincide with the 55 years of record available for the Big Hole River near Melrose is 52,008 acre-feet per year. The average annual long-term run-off coefficient for the drainage area, which is a granitic mountain watershed, is 0.4483.

The drainage area for the Fat Man site on Trail Creek is 48 square miles. Precipitation within the drainage area ranges from 18 to 50 inches per year giving a precipitation volume of 83,749 acre-feet per year. The product of the 83,749 acre-feet per year precipitation volume and the run-off coefficient of 0.4483 is an average annual water supply at the Fat Man site of 37,545 acre-feet per year. The estimated rate of discharge for a PMF at the Fat Man site is 95,000 cfs and the estimated PMF volume is 36,000 acre-feet.

RESERVOIR CAPACITY

The topographic potential of the Fat Man site is adequate to store more than 100,000 acre-feet of water. Thus, the topographic potential of the storage site greatly exceeds the average annual water supply of 37,545 acre-feet and provides ample opportunity for carry-over storage. Carry-over storage is water stored in amounts exceeding average annual supply for release during years of less than average annual supply. The relationship between elevation, dam height, and reservoir storage capacity at the Thin Man site is shown on table 25.

TABLE 25: Elevation-storage-capacity data for the Thin Man site on Trail Creek.

Elevation* (in feet)	Dam Height* (in feet)	Storage Capacity (in acre-feet)
6344	0	0
6360	16	2,230
6400	56	5,590
6440	96	27,950
6480	136	71,430
6520	176	135,910

* Developed from 7.5-minute U.S. Geological Survey topographic map with 40-foot contour interval.

RESERVOIR OPERATION

The effectiveness of different sizes of storage capacity in regulating the long-term average annual water supply for beneficial uses is expressed here as the percent control of the average annual supply. The percent control is the ratio of uncontrolled reservoir spills to the long-term average annual stream flow expressed as a percentage. Beneficial uses are irrigation (including conveyance losses and field losses) and instream uses. Irrigation requirements are based on the assumption of sprinkler irrigation of alfalfa in the upper Big Hole River basin with an average annual diversion requirement of 2.33 acre-feet per acre. The critical period for reservoir operation is based on the ten-year period of lowest recorded stream flow (1928-1937). The percent control or regulation obtained by different storage capacities at the Fat Man site is shown on table 26.

The percent control is shown for two demand assumptions. Under the column labelled "irrigation only," the reservoir is managed to supply a maximum instream flow of 400 acre-feet per month (6.7 cfs) in nonirrigation months and no instream flow during the irrigation season. The irrigation-only management does not satisfy instream flow requirements. The remainder of the water supply is allocated to irrigation use and instream flows consist of irrigation water releases during the irrigation season.

The management assumptions for the instream and irrigation column on table 26 allocate water to satisfy minimum levels of aquatic-habitat-quality flow requirements in nonirrigation months. Instream flows are satisfied by irrigation releases in irrigation months and uncontrolled spillways are assumed to satisfy high-flow requirements for instream use (which is not always true).

The maximum number of acres shown for both management assumptions is the maximum acreage provided with a full water supply in every year including the year of lowest flow. The year of lowest flow is assumed to be the firm dependable water supply upon which to base project design and economics. Acreages exceeding the maximum acres will not have a firm dependable water supply available and will suffer shortages in many years.

TABLE 26: Relationship between reservoir storage capacity and control of long-term average annual water supply for beneficial use during the ten-year period of low flows at the Fat Man site on Trail Creek.*

Reservoir Capacity (in acre-feet)	Percent Control			
	Irrigation Only	Maximum Acres	Instream & Irrigation	Maximum Acres
5,000	80.1	4,822	82.1	4,455
6,000	82.5	5,247	84.0	4,455
10,000	90.1	5,247	91.5	4,455
15,000	95.5	5,247	95.6	4,455
20,000	95.7	5,247	95.6	4,455
40,000	95.7	7,600	95.6	7,363
60,000	95.7	7,600	95.6	7,363
80,000	95.7	7,600	95.6	7,363
100,000	95.7	11,616	95.6	11,462

* Average annual supply equals 37,545 acre-feet.

COST ESTIMATES

Cost estimates presented herein are based on methodology and cost curves presented in Appendix A of the Series 150 Estimating Reclamation Instructions, published by the Bureau of Reclamation, and Bureau of Reclamation Construction Cost Trends for January 1980. The cost estimates as presented are based on generalized data and must be regarded as reconnaissance level cost estimates.

The relationship between annual cost and reservoir storage capacity is shown on figure 8. The annual costs include annual repayment based a 6 7/8 discount rate, a 40-year project life, and $20,000-per-year operation and maintenance costs. The costs apply solely to the embankment, outlet works, spillway, and appurtenant structures, and do not include downstream conveyance structures for delivery of water to project lands. Also, the costs do not include land acquisition. The spillway costs for the Trail Creek sites are based on criteria for a high-hazard dam requiring PMF discharge capacity.

The costs for the Fat Man site include 5.3 miles of highway relocation in rugged mountainous terrain requiring excavation by blasting at an estimated cost of $5.3 million. Spillway costs are reduced substantially by using surcharge to store the PMF flood and eliminating spillway structure costs. Surcharge requires that the dam embankment be constructed to a height adequate to store the maximum storage requirement for normal operation plus the volume of the PMF. The additional embankment costs for surcharge capacity are considerably less than the costs for an emergency spillway of equivalent capacity. The annual-costs-versus-capacity curve on figure 8 includes surcharge requirements.

The estimated annual costs for the size of structures shown on table 26 and the estimated annual costs per acre-foot for the

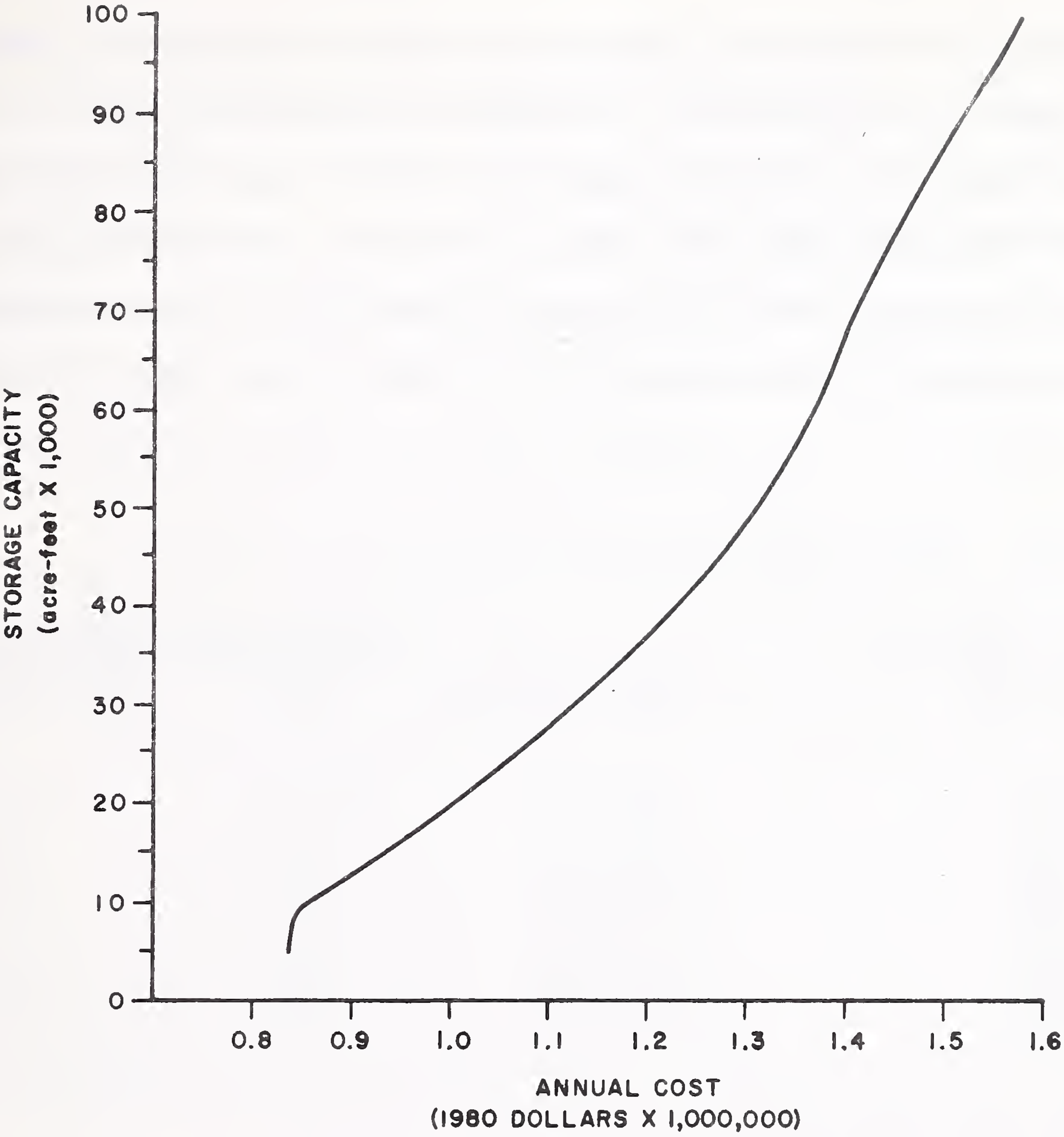


FIGURE 8. Annual costs compared to reservoir storage capacity at the Fat Man site on Trail Creek.

storage capacities shown on table 26 are shown on table 27. The use of grant funds from the Bureau of Outdoor Recreation or the assignment of benefits to flood control, fishery, or recreation uses would reduce the cost per acre-foot. The costs per acre-foot on table 27 may be converted to costs per irrigated acre by multiplying the costs by the average annual diversion requirement of 2.33 acre-feet per acre.

TABLE 27: Annual costs for different sizes of dams at the Fat Man site.*

Reservoir capacity (including surcharge) (in acre-feet)	Annual costs (in 1980 dollars)	Annual costs per acre: Irrigation only	Annual costs per acre: Irrigation and instream
5,000	837,400	$ 75	$ 81
10,000	853,100	70	82
15,000	937,500	77	90
20,000	1,006,250	82	97
40,000	1,227,500	69	72
60,000	1,371,250	77	80
80,000	1,462,500	83	85
100,000	1,577,500	58	59

* Dam sizes are those shown on table 26.

The cost per acre-foot as shown on table 27 might be further reduced if supplemental irrigation were used. Supplemental irrigation is the delivery of less than full consumptive-use requirements to a crop and is basically the type of irrigation currently being used in the upper Big Hole River basin. For example, if the project were designed on the basis of providing only 60 percent of the crop's consumptive-use requirement, the maximum acre-foot reservoir (table 26) would be 8,037 and 7,425 acres (compared to 4,822 and 4,455 acres). The costs per acre (table 27) would be $45 and $48 compared to $75 and $81. However, the benefits gained in crop production due to supplemental irrigation may not offset the increased costs for irrigation.

REFERENCE

U.S. Geological Survey, 1974. Surface Water Supply of the United States, 1966-1970: U.S. Geol. Survey Water-Supply Paper 2116.

6. FRENCH CREEK DAM SITE

OVERVIEW

The French Creek site is located in section 16, T.2N., R.12W. Previous investigations by Brown et al. (1979) raised questions regarding the possibility of a major fault traversing the length of the reservoir area and passing through the foundation at the axis of the potential dam site. Detailed geologic mapping conducted for this study in the summer of 1980 revealed that the fault does not exist. The detailed field mapping did locate a major thrust fault in the reservoir area; however, the conclusion of the 1980 field work is that the proposed tributary storage site on French Creek is suitable from the standpoint of geology and does not present any unusual or extreme geologic or engineering problems.

The potential dam site is located in an area of Precambrian quartzite bedrock that appears to present little potential for seepage loss. The upper reach of the reservoir area is contained by relatively impermeable Tertiary sediments. The potentially limited availability of materials sources for earthfill embankment construction at the site may require use of artificial cutoff cores in an earthfill dam or use of an alternative design such as a rockfill dam. If special cutoffs or alternative designs are required, project costs may be increased somewhat above the earthfill embankment costs estimated in this report.

The topographic potential at the French Creek site provides the opportunity to store a maximum of 28,855 acre-feet or about 1.6 times the average annual water supply of 17,957 acre-feet. The drainage area providing water supply to the French Creek site is 49.7 square miles. The peak discharge estimated for the probable maximum flood (PMF) at the dam site is 96,000 cfs and the PMF volume is 38,000 acre-feet. The presence of private cabins, a state highway, and a ranch home and outbuildings in the potential flood path of the French Creek site result in all spillway designs and cost estimates for the site being based on the PMF event. If detailed flood routing studies for a dam failure at the site indicate that the spillway designs based on a lesser hydrologic event than the PMF are acceptable, project costs would be reduced accordingly.

The percentage of the long-term average annual supply that would be regulated for beneficial use (low-level instream requirements and irrigation) during the projected ten-year critical period of lowest stream flow is shown on table 28 for different reservoir capacities including reservoir capacities that provide carry-over storage in excess of average annual supply.

TABLE 28: Regulation, irrigated acreage, and costs per acre-foot for reservoir capacities at the French Creek site.

Reservoir Capacity (acre-feet)	Percentage of Average Annual Supply Required	Acre-feet Regulated	Maximum Irrigated Acres	Cost per Acre-foot (1980 dollars)
5,000	92.2	16,556	2,224	68
10,000	95.6	17,167	2,224	93
15,000	95.6	17,167	2,337	99
20,000	95.6	17,167	3,521	73
28,855	95.6	17,167	3,521	114

The maximum irrigated acres shown on table 28 are the maximum acreages that can be provided with a full irrigation diversion requirement without any shortages in the driest year. The costs on table 28 assume that all costs are born by irrigation with no sharing in costs by other uses such as flood control, recreation, or fish and wildlife enhancement.

Other considerations at the French Creek site include agreements pertaining to use of the land. Purchase of the former Mount Haggin Ranch was funded by a Nature Conservancy grant to the Department of Fish, Wildlife and Parks. In order to obtain the Nature Conservancy funding, the Department of Fish, Wildlife and Parks agreed to manage the Mount Haggin Ranch lands solely for the enhancement and benefit of fish, wildlife, and recreation, and primarily as range for game management. The agreement with the Nature Conservancy requires that reduction in benefits to one of the areas which must be considered must be offset by increased benefits to one of the others.

ENGINEERING-GEOLOGIC INVESTIGATIONS

The French Creek dam site was visited on June 17, 1980, by Mike Kaczmarek, chief geologist for Morrison-Maierle, Inc., and Roger Noble, hydrogeologist for the Water Sciences Bureau, Montana Department of Natural Resources and Conservation. Additional field work was accomplished by Mike Kaczmarek on July 29, 1980. The potential dam site on French Creek had been examined previously by Roger Noble and others and preliminary engineering-geologic evaluations completed. The purpose of the June 17 and July 29, 1980, fieldwork was to expand on the preliminary site evaluation. The specific goal was to determine the bedrock geologic structure at the foundation and abutments with emphasis on determining the presence or absence of major faulting parallel and coincident with the French Creek valley alignment.

General Geology

The local area of the potential tributary storage dam site on French Creek is a steep-walled mountain valley cut into Precambrian quartzite. The valley walls slope at an average of 30 degrees from horizontal and exhibit numerous discontinuous quartzite ledges 3 to

25 feet high. Surficial deposits on the valley walls consist of a few feet of colluvial soil and small rock talus cones and aprons at the foot of most slopes. The valley floor is a broad, flat, poorly drained physiographic floodplain consisting of unconsolidated alluvium of unknown thickness. The valley floor is graded at about 22 to 23 feet per mile.

The path of the French Creek valley through a relatively resistant mass of quartzite some 400 feet high (figure 9), in preference to easily erodible Tertiary sediments in the SE1/2, section 9, has resulted in speculation that the French Creek valley may be fault controlled (Brown et al. 1979). The hypothetical fault would parallel the alignment of the valley and would pass through the foundation area of the potential dam site.

STRATIGRAPHY

The bedrock strata at the French Creek site consist predominantly of quartzite and are part of the Belt Series. The Belt Series, viewed en masse, is a relatively monotonous assemblage of very thick units composed mainly of fine-grained clastic rocks. Nearly all contacts are gradational and broad similarities exist between most units Locally, variations in detail are numerous and individual subdivisions can be recognized and mapped. The formation names differ from one area to another and in some cases the locally

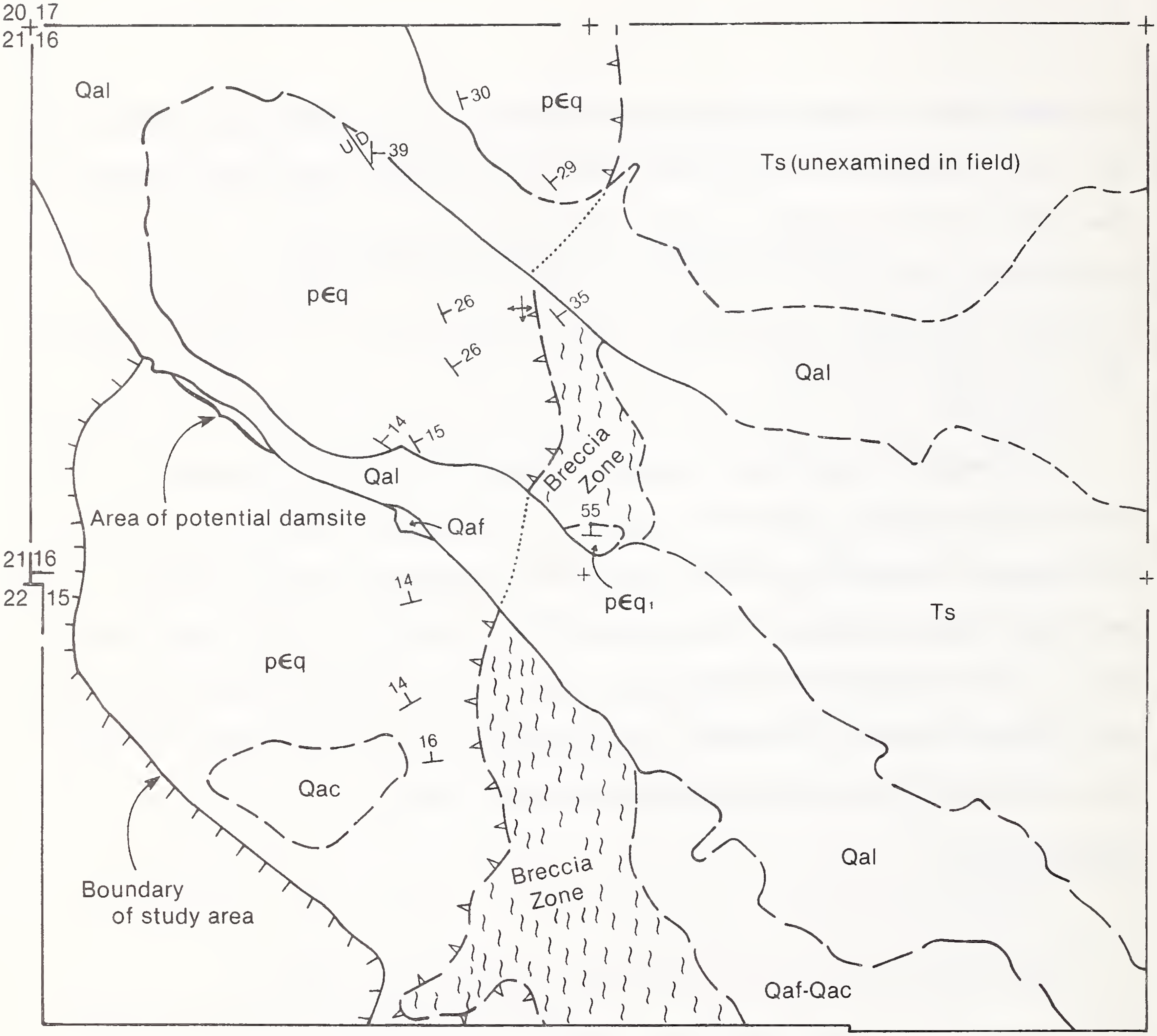


FIGURE 9. Reconnaissance geologic map of the French Creek site.

— Geologic Contact, Dashed Where Approximate

— Thrust Fault, Barbs on Thrust Plate

— High Angle Fault

— Strike and Dip, Dip Shown in Degrees

— Breccia Zone

Qal — Quaternary Alluvium

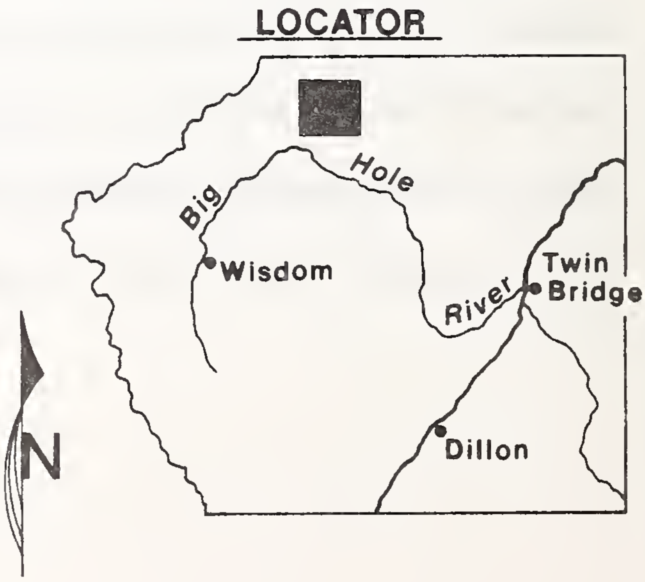
Qaf — Quaternary Alluvial Fan

Qac — Quaternary Colluvium

Ts — Tertiary Sediments

p€q — Precambrian Quartzite, Clast-Bearing

p€q₁ — Precambrian Quartzite, Non-Clast-Bearing



used subdivisions are of limited extent. Lateral variations are an outstanding characteristic of the Belt Series. Lateral variations combined with differences in locally used formation names render direct correlation of formational units across wide distances questionable, if not impossible, without adequate mapping to establish the lateral continuity of the units.

Ross (1963) and earlier investigators (Ross et al. 1955) assign the Belt Series rocks in the area east of French Creek to the Missoula Group. The formational units of the Missoula Group were established based on exposures near Missoula, and on exposures of laterally equivalent rocks in the Belt Mountains east of Helena. The subdivisions based on exposures near Missoula are the Mount Shields, Bonner, McNamara, Garnet Range, and Pilcher Formations (Wallace et al. 1977), as modified from previous investigations (Ross 1963, Nelson and Dobell 1961, Clapp and Deiss 1931). The subdivisions based on exposures in the Belt Mountains are the Greyson, Spokane, and Empire shales, the Helena Limestone, the Marsh Shale, and the Greenhorn Mountain Quartzite (Ross 1963).

Significant differences in lithology and unit thickness exist between the laterally equivalent units of the Missoula Group as defined at Missoula and in the Belt Mountains. In general, the rocks observed during the June 17 and July 29, 1980, field trips do not resemble the overall characteristics of the Missoula Group in the Belt Mountains type locality. The Belt strata observed along French Creek exhibit characteristics very similar to those observed in the Garnet Mountains east of Missoula (Morrison-Maierle, Inc. 1978). In his discussion of the distribution of the Missoula Group in Montana, Ross (1963) states:

> Reconnaissances by Nelson, Dobell, and the writer lead to the opinion that some of the formations recognized in the Bonner quadrangle persist southeastward to and beyond Philipsburg.

and,

> From near Philipsburg southward almost to lat. 45 degrees rocks with the characteristics of the Missoula group (as used in the Missoula area) have been seen in reconnaissance by the writer . . .

The nomenclature used for the Missoula Group in this report will be that of Wallace et al. (1977). The strata comprising the abutments, bedrock foundation, and most of the area contiguous to the proposed dam site consist of quartzite with subordinate amounts of siltite and resemble the Garnet Range Formation. The basis for this comparison is the similarity of lithologic and bedding structure characteristics observed in the strata at French Creek with characteristics of the Garnet Range Formation observed in the Garnet Mountains east of Missoula (Morrison-Maierle, Inc. 1978).

Quartzite is dominant at the top of the Garnet Range Formation near Missoula where it is blocky to massive in splitting properties, very hard, and in freshly broken exposures, medium to dark gray, slightly micaceous, and with a brown weathering rind. Diagnostic features of the Garnet Range Formation quartzites observed both near Missoula and in the quartzite at French Creek include laminated and low-angle crossbedding and micaceous bedding planes. The siltites observed at French Creek are laminated, exhibit flaggy splitting properties, and contain numerous mud clasts of rip-up structures as do the quartzites to a lesser extent. The rip-up structures are fragments of older soft sediments that were disturbed by current action during deposition of the quartzite sands. The rip-up structures are diagnostic of the Garnet Range Formation, the McNamara Formation, and parts of the Mount Shields Formation. The clasts in the McNamara Formation in the Missoula area have been partially or totally replaced by chert, whereas those in the Garnet Range and Mount Shields Formations are generally unaltered, as are those in the quartzite at French Creek.

The lack of mapping correlation with units to the north makes it impossible to assign a positive formation classification to the quartzite beds at French Creek. The likelihood of lateral variation in formational characteristics between mapped areas to the north and unmapped areas at French Creek makes correlation on the basis of lithology and internal structure highly unreliable. The likelihood of lateral variation introduces the possibility that the thick quartzite sequence at French Creek may be laterally equivalent to more than one formation in the mapped units to the north.

STRUCTURE

The dominant geologic structure in the vicinity of the potential French Creek dam site is a major breccia zone that trends east-west along the northern edge of sections 15 and 16 (figure 9). The breccia zone is 1/4 to 1/2 mile from the potential dam site area and does not affect the integrity of the dam site foundation.

The breccia zone is expressed as a zone of highly brecciated quartzite at least 1,000 feet wide. The strike and dip of the strata in the breccia zone could be measured at only one location in the areas examined. The outcrop where strike and dip were measured is grayish-orange to buff, thick to massive bedded, and fine- to medium-grained quartzite in the SE1/4, SE1/4, SE1/4, section 9, T.2N., R.12W. The quartzite is markedly different from the rip-up, clast-bearing quartzite south of the breccia zone in section 16 and displays characteristics similar to the Bonner Formation in other areas. The grayish-orange quartzite outcrop north of the breccia zone strikes N 2 degrees E and dips 54 degrees to the west.

The grayish-orange quartzite is highly brecciated in zones 4 to 5 feet thick parallel to the bedding and unbrecciated quartzite in the outcrop displays slatey cleavage perpendicular to the bedding.

Similar outcrops of brecciated quartzite are presented in the NE1/4, SW1/4, NE1/4 and SE1/4, NW1/4, NE1/4 of section 15 on the east side of a small canyon (figure 9) and in the breccia zone in the NE1/4, NW1/4, NE1/4 of section 15 and the SE1/4, SE1/4 of section 10.

The breccia zone appears to be the trace of a major thrust fault. The clast-bearing quartzite on the south side of the breccia zone comprises a south to north displaced thrust plate. The grayish-orange, clast-free quartzite in the breccia zone is part of a sole plate that was overridden. Some brecciated clast-bearing quartzite in the SE1/4, SE1/4 of section 10 is the brecciated base of the thrust plate. The foregoing thrust fault interpretation is compatible with the orientation of small drag folds and low-angle reverse faults exposed along the highway in the NW1/4 of section 16, which indicate compressional forces exerted from the south in the clast-bearing quartzite.

The interpretation of the breccia zone as a south to north thrust fault zone is compatible with the locally observed geology. However, other interpretations may be possible and geologic investigation of a regional extent is required to determine the relationship of the fault to regional structures such as the Willow Creek fault to the east. The fault does not affect the foundation of the French Creek dam site and is not a potential seepage path in the reservoir area. The nature, extent, and geologic age of the fault would be a consideration in the seismic design of an earthfill or rockfill embankment at French Creek.

Quartzite beds south of the breccia zone on the east side of the French Creek valley in the NW1/4 of section 15 strike generally southeast to south-southeast and dip 14 to 16 degrees southwest. Quartzite beds at the same elevations on the opposite side of the valley in the NE1/4 of section 16 strike northeast and range in dip from 14 to 16 degrees near the base of the valley wall to 26 to 30 degrees at the top of the valley wall and west of the highway (figure 9). Reliable strike and dip measurements in the south half of section 16 were not obtained. Nevertheless, general trends are southeast strikes and gentle southwest dips. Reliable dips were not obtained in the quartzite of the breccia zone (except at the SE1/4, SE1/4, SE1/4, section 9); however, the outcrops in the breccia zone display a strong north-south strike.

The foregoing structure (south of the breccia zone) as displayed on figure 9 is not easily explained by any type of fault or multiple faults. Although direct stratigraphic correlation is not possible across the French Creek valley due to the lack of marker horizon, the general lithology across the valley is compatible and there is no evidence of a fault breccia zone or shear zones parallel to the valley trend that might indicate fault displacement.

The most reasonable explanation of the strike and dip relationships in the beds south of the breccia zone is differential folding of the thrust plate. The conclusion of the field investigation is that the French Creek valley in section 16, T.2N., R.12W. follows the axial trace of an arcuate monoclinal fold and there is no fault parallel to the valley alignment.

ABUTMENTS AND FOUNDATION

The abutments at the French Creek dam site consist of massive to thick bedded quartzite. The strike and dip of the quartzite is shown on figure 9. The quartzite is jointed at the weathered surface of outcrops but the joints probably become quite tight below the weathering zone. Exploratory drilling and permeability tests are required to determine the openness and permeability of the joints below the weathered zone on both abutments. The jointed quartzite is not anticipated to present any unusual or unacceptable seepage problems.

Small talus cones and talus aprons are present at numerous locations along the margin of the alluvial valley floor. The talus ranges in size from less than 6 inches to about 24 inches in mean dimension and consists of blocky quartzite fragments that have fallen from the valley walls. The talus is estimated to range from 10 to 15 feet thick in most places.

Field evidence indicates the talus rests upon the alluvial sediments in the valley floor and does not extend more than a few feet below the land surface. The evidence of the talus thickness is provided by numerous toe bulges or pressure ridges at the toe of the talus slopes and related subsidence or sag depressions in the talus piles. The toe bulges are pressure ridges where the weight of the talus resting on the unconsolidated, fine-grained surficial alluvium has caused shear failure and mud heaving in the alluvium. If the talus deposits extended to depth beneath the alluvium, there would be no evidence of loading and shear failure in the alluvium.

The foundation material in the valley floor consists of unconsolidated alluvial gravel, sand, silt, and clay of unknown thickness. The Bureau of Reclamation predicted a range of thickness of 10 to 20 feet (Brown et al. 1979); however, data was not provided to substantiate the estimate. The alluvial materials are expected to be pervious and would require a partial or full core trench cutoff to control seepage losses and seepage pressures. A foundation investigation based on test holes drilled to bedrock would be required to determine the thickness, stratification, and permeability of the alluvium.

RESERVOIR AREA

The reservoir area is floored with alluvium. The reservoir banks consist of quartzite bedrock in most of section 16 (figure 9). The joints and bedding in the quartzite provide slight potential for bank storage and seepage losses. Test holes in the abutment areas would provide information that may be used to predict bank storage and seepage losses.

The portion of the reservoir area upstream from section 16 is contained by Tertiary sediments (figure 9). The Tertiary sediments are predominantly fine-grained materials consisting of relatively impervious silts and very fine-grained sand mixed with clayey volcanic ash. The Tertiary sediments provide little or no opportunity for significant bank storage or seepage loss.

MATERIALS SOURCES

The Tertiary sediments and the valley floor alluvium are the only two potential sources of earth materials that may be readily excavated and used for earthfill embankments. The suitability of the alluvium for use in a homogeneous or zoned-dam embankment is unknown; however, the alluvium is the most promising potential source of impervious embankment material. The uncertainty regarding the thickness of the alluvium also reflects on the potential availability of the alluvium in the reservoir area. Excavation of the alluvium as a source of borrow would require dewatering of the borrow area.

The Tertiary sediments are readily available for excavation without dewatering and are available in large quantities. However, the fine-grained nature of the Tertiary sediments make them highly susceptible to piping. The Tertiary sediments are not recommended for use as an impervious core or embankment prior to extensive testing for susceptibility to piping. If tests confirm susceptibility to piping, the use of Tertiary sediments in the dam embankment would require a positive cutoff wall in the dam and foundation such as concrete or other similar material. Use of the Tertiary sediments in the embankment under conditions of significant piping potential would also limit the potential to control seepage pressures with pervious drains.

A third source of embankment material may be the quartzite bedrocks which are suitable for construction of a rockfill dam. A rockfill dam would also require an impervious membrane either as an external upstream face blanket or an internal core. The uncertainties regarding the use of the valley floor alluvium and Tertiary sediments for impervious fill apply equally to their use for impervious membrane on a rockfill dam. Construction of a rockfill dam may require use of an artificial membrane such as concrete, asphalt, or other materials.

The alluvium is a relatively promising source of mineral aggregate for concrete and protective shell material. The quartzite bedrocks are also a suitable source area for crushed aggregate but would require quarrying by drilling and blasting. The blocky quartzite is also a suitable source of riprap.

Hydrology

The drainage area providing water supply to the French Creek site is 49.7 square miles. Precipitation in the drainage area ranges from 14 to 30 inches, which results in an average annual precipitation volume of 50,691 acre-feet. The watershed contains 11.5 square miles of mountain watershed with a run-off coefficient of 0.3696. The product of the average annual precipitation volume and the run-off coefficients is 17,957 acre-feet per year of average annual water supply. The PMF discharge rate for the French Creek site is 96,000 cfs and the PMF volume is 38,000 acre-feet.

RESERVOIR CAPACITY

The topographic potential of the French Creek site is 28,855 acre-feet or about 1.6 times the average annual water supply. The 28,855 acre-feet of storage would require construction of about

1,270 feet of dike a maximum of 20 feet high along the west side of the reservoir in the SE1/4 of section 9, T.2N., R.12W. from elevation 6,010 feet to elevation 6,030 feet. The relationship between elevation, dam height, and reservoir storage capacity at the French Creek site is shown in table 29.

Table 29: Elevation-storage-capacity data for the French Creek site.

Elevation* (in feet)	Dam height* (in feet)	Storage capacity (in acre-feet)
5,895	0	0
5,900	5	4
5,920	25	278
5,940	45	1,431
5,960	65	4,191
5,980	85	9,109
6,000	105	17,025
6,020	125	28,855

* Developed from 7.5-minute U.S. Geological Survey topographic map with 20-foot contour interval.

RESERVOIR OPERATION

The effectiveness of different sizes of storage capacity in regulating the long-term annual water supply for beneficial uses is expressed here as the percent control of the average annual supply. The percent control is the ratio of uncontrolled reservoir spills to the long-term average annual stream flow expressed as a percentage. Beneficial uses are irrigation (including conveyance losses and field losses) and instream uses. Irrigation requirements are based on the assumption of sprinkler irrigation of alfalfa in the upper Big Hole River basin with an average annual diversion requirement of 2.33 acre-feet per acre. The critical period for reservoir operation is based on the ten-year period of lowest recorded stream flow (1928-1937). The percent control or regulation obtained by different storage capacities at the French Creek site is shown on table 30.

The percent control is shown for two demand assumptions. Under the column for irrigation only, the reservoir is managed to supply a maximum instream flow of 250 acre-feet per month (4.2 cfs) in nonirrigation months and no instream flow during the irrigation season. The irrigation only management does not satisfy instream flow requirements. The remainder of the water supply is allocated to irrigation use, and instream flows consist of irrigation water releases during the irrigation season.

The management assumptions for the instream and irrigation column on table 30 allocate water to satisfy minimum levels of aquatic habitat-quality flow requirements in nonirrigation months. Instream flows are satisfied by irrigation releases in irrigation months and uncontrolled spills are assumed to satisfy high flow requirements for instream use (but this would not always be true).

The maximum number of acres shown for both management assumptions are the maximum acreages provided with a full water supply in every year, including the year of lowest flow. The year of lowest flow is assumed to be the firm dependable water supply upon which to base project design and economics. Acreages exceeding the maximum acres will not have a firm dependable water supply available and will suffer shortages in many years.

TABLE 30: Relationship between reservoir storage capacity and control of long-term average annual water supply for beneficial use during the ten-year period of low flows at the French Creek site.*

Reservoir Capacity (in acre-feet)	Percent Control			
	Irrigation Only	Maximum Acres	Instream and Irrigation	Maximum Acres
5,000	92.0	2,333	92.2	2,224
10,000	95.7	2,333	95.6	2,224
15,000	95.7	2,365	95.6	2,337
20,000	95.7	3,528	95.6	3,521
28,855	95.7	3,528	95.6	3,521

* Average annual water supply is 17,957 acre-feet.

COST ESTIMATES

Cost estimates presented herein are based on methodology and cost curves presented in Appendix A of the Series 150 Estimating Reclamation Instructions published by the Bureau of Reclamation and Bureau of Reclamation Construction Cost Trends for January 1980.

The cost estimates as presented are based on generalized data and must be regarded as reconnaissance level cost estimates.

The relationship between annual costs and reservoir storage capacity is shown on table 30. The annual costs include annual repayment based on a 6-7/8 percent discount rate, a 40-year project life, and $20,000-per-year operation and maintenance costs. The costs apply solely to the embankments, outlet works, spillway, and appurtenant structures and do not include downstream conveyance structures for delivery of water to project lands. The project costs on table 30 do not include land acquisition but do include relocation costs for as much as 3 miles of highway at appropriate storage levels. The spillway costs for the French Creek site are based on criteria for a high hazard dam requiring PMF discharge capacity.

The estimated costs for the size of structures shown on table 30 are listed on table 31. The estimated annual costs per acre-foot for the storage capacities shown on table 30 are also shown on table 31. The costs shown on table 31 assume all costs are reimbursed by irrigation. The use of funds from the Bureau of Outdoor Recreation or the assignment of benefits to flood control, fishery, or recreation uses would reduce the cost per acre-foot for irrigation. The costs per acre-foot on table 31 may be converted to costs per irrigated acre by multiplying the costs by the average annual diversion requirement of 2.33 acre-feet per acre.

TABLE 31: Annual costs for different sizes of dams at the French Creek site.*

Reservoir capacity (in acre-feet)	Annual costs (in 1980 dollars)	Annual costs per acre-foot	
		Irrigation only	Irrigation and Instream
5,000	351,016	65	68
10,000	481,787	89	93
15,000	540,874	98	99
20,000	599,301	73	73
28,855	936,000	114	114

* Dam sizes are those shown on table 30.

REFERENCES

Brown, L.L., Rediske, T.G., and Noble, R.A., 1979. Preliminary design review of potential off-stream reservoir sites in the Big Hole River basin: Water Sciences Bureau, Dept. of Natural Resources and Conservation, Montana.

Clapp, C.H., and Deiss, C.F., 1931. Correlations of Montana Algonkian Formations: Geol. Soc. America Bull., v. 42, no. 3, pp. 673-695.

Morrison-Maierle, Inc., 1978. Geologic Survey and Land Classification of the Blackfoot Planning Unit, Garnet Resource Area, with a section of Geologic Resources by Charles S. Robinson & Associates: Prepared for U.S. Bureau of Land Management, Missoula, Montana.

Nelson, W.H., and Dobell, J.P., 1961. Geology of the Bonner Quadrangle, Montana: U.S. Geol. Survey Bull., 111-F, 235 pp.

Ross, C.P., 1963. The Belt Series in Montana: U.S. Geol. Survey Prof. Paper 346, 122 pp.

Ross, C.P., Andrews, D.A., and Whitkind, I.J., 1955. Geologic Map of Montana: U.S. Geol. Survey. Scale 1"500,000.

Wallace, C.A., Klepper, M.R., and Scarborough, D.M., 1977. Preliminary Reconnaissance Geologic Maps of the Garnet Range, Western Montana: U.S. Geol. Survey, Open-File Report 77-529.

7. JOHNSON CREEK DAM SITE

OVERVIEW

The Johnson Creek site is located in section 30, T.1S., R.16W. on the west flank of the upper Big Hole River basin. The geology of the potential tributary storage site is very favorable to construction of an earthfill dam and suitable sources of select construction materials are readily available at the site. The topography at the site provides the opportunity to develop about 150,000 acre-feet of storage capacity. The storage capacity of a dam 180 feet high would be 150,168 acre-feet.

The watershed draining to the Johnson Creek site is 37.9 square miles and yields a calculated average annual water supply of 28,363 acre-feet. The estimated probable maximum flood (PMF) peak discharge is 69,000 cfs and the estimated PMF volume is 20,000 acre-feet. Similar to the Trail Creek site, spillway construction costs based on PMF criteria can be substantially reduced by using surcharge to store a PMF event rather than passing the PMF through an emergency spillway. Construction costs related to PMF spillway criteria might be further reduced if detailed flood path studies resulted in downgrading the hazard classification of the dam so that a smaller emergency spillway or surcharge volume were acceptable.

The percentage of the long-term average annual water supply that would be regulated for beneficial use (low-level instream requirements and irrigation) during the projected ten-year critical period of lowest stream flows is shown on table 32 for different reservoir capacities including reservoir capacities that provide carry-over storage in excess of average annual supply.

The maximum irrigated acres shown on table 32 are the maximum acreages that can be provided with a full irrigation diversion requirement without any shortages in the driest year. The costs per acre-foot on table 32 assume that all costs would be born by irrigation with no sharing in costs by other uses such as flood control, recreation, or fish and wildlife enhancement.

An inventory performed by DNRC indicates that 26,261 acres of presently irrigated lands could be served by the Johnson Creek site. The 26,261 acres of presently irrigated lands currently suffer water supply shortages in most years. The DNRC inventory reveals that an additional 17,805 acres of land are suitable for irrigation cropping but are not presently irrigated and could be served from the Johnson Creek site. The irrigated and irrigable lands that could be served from the Johnson Creek site are essentially the same lands that could be served from the Trail Creek sites because the point of project diversion for both the Johnson Creek and Trail Creek sites is downstream from the sites on the North Fork of the Big Hole River.

TABLE 32: Regulation, irrigated acreage, and costs per acre-foot for reservoir capacities at the Johnson Creek site.

Reservoir Capacity (acre-feet)	Percentage of Average Annual Supply Regulated	Acre-Feet Regulated	Maximum Irrigated Acres	Cost per Acre-Foot (1980 dollars)
5,000	85.2	24,265	3,513	58
10,000	95.0	26,945	3,513	65
15,000	95.6	27,115	3,513	69
20,000	95.6	27,115	3,513	76
30,000	95.6	27,115	5,561	128
40,000	95.6	27,115	5,561	143
60,000	95.6	27,115	5,561	167
80,000	95.6	27,115	10,569	100
100,000	95.6	27,115	10,815	109

The demands resulting from the shortages suffered by presently irrigated lands combined with the demands associated with the additional irrigable lands exceed the firm annual water supply that could be provided from the Johnson Creek site. The combined demands associated with the presently irrigated and potentially irrigable lands exceed the water supply of the Fat Man site on Trail Creek combined with the Johnson Creek water supply by 12,925 acre-feet (5,546 potential acres of irrigated land), assuming a reservoir capacity of 100,000 acre-feet at both sites or 200,000 acre-feet of total storage.

ENGINEERING-GEOLOGIC INVESTIGATION

The potential tributary storage site on Johnson Creek in section 30, T.1S., R.16W., was visited on June 16, 1980, by Mike Kaczmarek, chief geologist for Morrison-Maierle, Inc., and Roger Noble, hydrogeologist for the Water Sciences Bureau, Montana Department of Natural Resources and Conservation. The purpose of the visit was to conduct an engineering-geologic evaluation of the potential dam site. The engineering-geologic evaluation was accomplished by field inspection of the earth materials at the site and by geologic mapping in the vicinity of the axis of the potential dam site.

General Geology

The potential dam and reservoir site on Johnson Creek is located in Tertiary valley fill sediments on the western margin of the Big Hole valley. The valley fill sediments in the local vicinity of the potential dam site consist of fluvially bedded sands, gravels, and gravelly silt, sand, and clay. The sediments lap onto the mountainous granitic terrain to the west and evidently represent a series of coalescing fans that developed along the western edge of the ancestral Big Hole valley in Tertiary time and, as such, the Tertiary sediments are fanglomerates. There is no visible evidence of faulting in the local area of the dam site although the bedding orientation of the Tertiary-aged sediments reflects mild structural deformation. The gentle dip of the stratification is upstream into the reservoir area. Little geologic work has been accomplished along the mountain front and the nature of major faulting, if any, is not known. The mountainous area west of the site consists of the intrusive rocks of the Idaho batholith which is a relatively stable geologic environment in regards to major faulting.

Three different geologic units were observed and mapped at the Johnson Creek site and designated as Recent alluvium, Pleistocene terrace gravel, and Tertiary sediments (figure 10). An additional mapping unit shown on figure 10 represents landslide deposits that consist of Tertiary sediments displaced by a slope failure.

Exposures of the Recent alluvium at the site and along Johnson Creek in general are very poor. The Recent alluvium appears to consist predominantly of sand and gravel in surface exposures and probably contains lesser amounts of silt and clay lenses. The thickness of the alluvium and the nature of the deeper alluvium are unknown.

Extremely bouldery and cobbly terrace gravels at approximately elevation 6,380 feet and higher form an extensive pediment on an erosional surface cut into the underlying Tertiary sediments. The bouldery terrace gravels are tentatively designated herein as Pleistocene terrace gravel. The base of the Pleistocene terrace

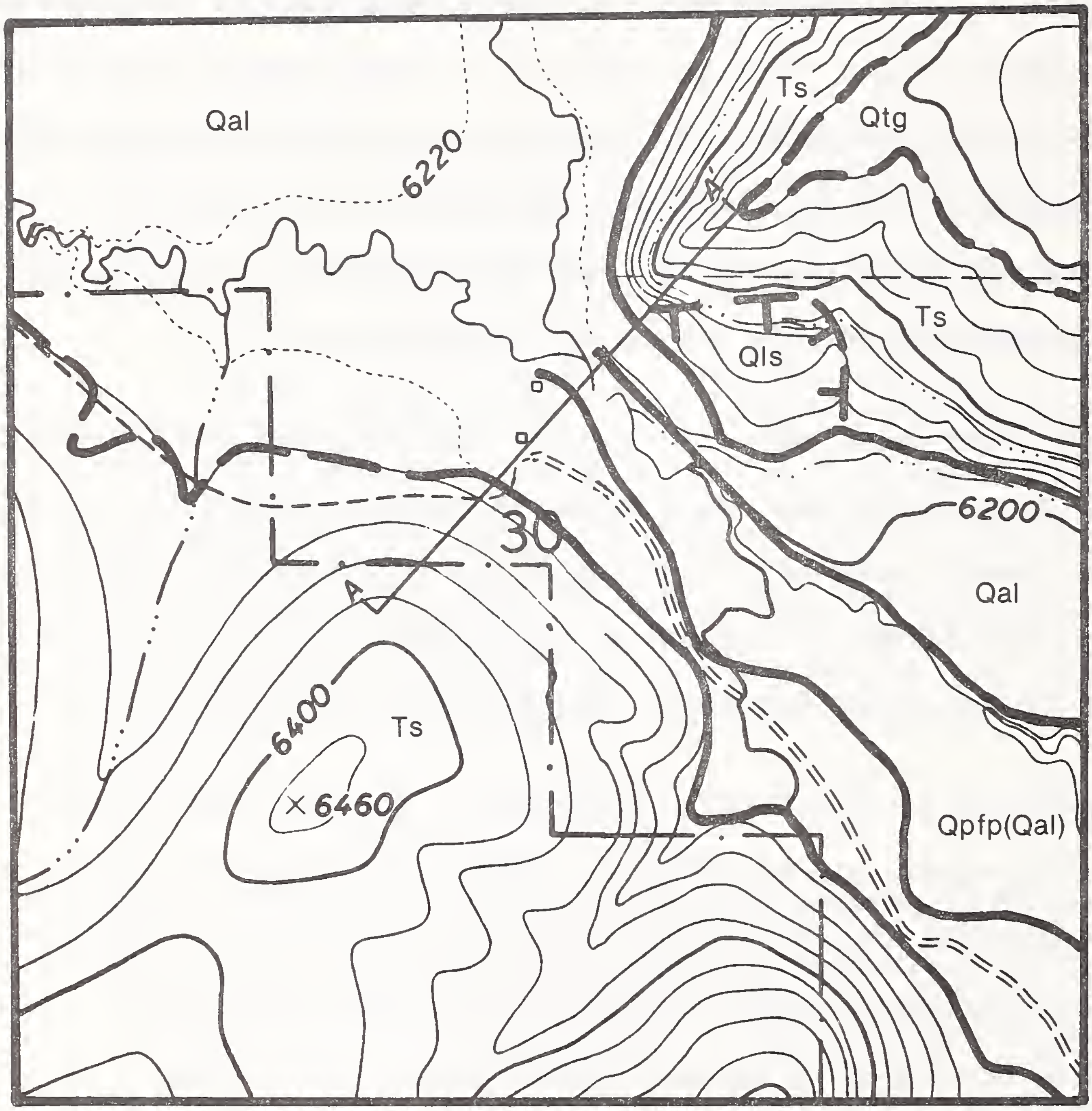


FIGURE 10. Reconnaissance geologic map of the Johnson Creek site. (SECTION 30, T. 1S., R. 16W.)

Qal — Recent Alluvium
Qpfp (Qal) — Physiographic Flood Plain
Qls — Landslide Deposits
Qtg — Pleistocene Terrace Gravel
Ts — Tertiary Sediments
━━━ — Geologic Contact
┳ ┳ — Landslide Headscarp
A—A' — Geologic Cross Section

Scale
Map represents one square mile

N

gravel is topographically higher than the potential storage area of the Johnson Creek dam site.

Sediments of Tertiary age form almost all of the potential reservoir bank area and underlie the Recent alluvium in the floor of the potential reservoir area (figure 11). The sediments are termed Tertiary sediments in this report. The Tertiary sediments consist of sandy and silty, sandy gravel lenticularly interbedded with silty and clayey, gravelly sand and sandy, silty lean clay. Individual lenses are less than 5 feet thick in most outcrops and crude fluvial stratification and imbrication are evident. The lateral extent of the individual lenses is not evident in the field. The coarse-grained gravel materials classify as GW and GM soils in the Unified Soil Classification (table 33) for engineering purposes. Most of the gravely sands classify as SM soils in the Unified Soil Classification (table 33) and lesser amounts of CL and some ML soils are also present. The gravels consist chiefly of high-grade metamorphic rocks and mica is abundant in all the fine fractions in the Tertiary sediments.

ABUTMENTS AND FOUNDATION

The left and right abutments of the Johnson Creek site consist of Tertiary sediments. The right abutment is heavily forested and the surface materials consist of mass wasting deposits that are

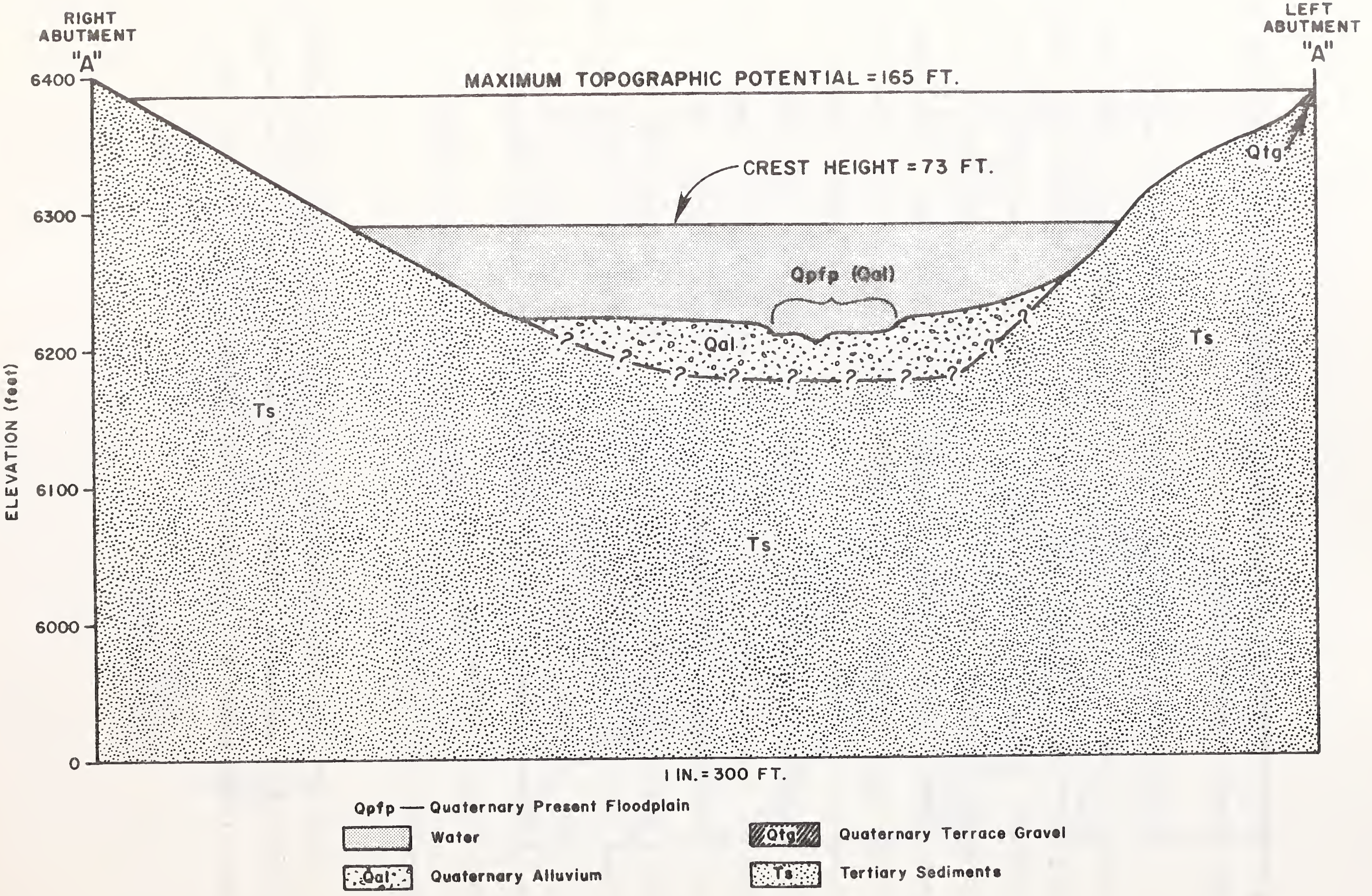


FIGURE 11. Geologic cross section (A-A) of the Johnson Creek site.

TABLE 33. Unified Soil Classification for engineering purposes.

FIELD IDENTIFICATION PROCEDURES (Excluding particles larger than 3 inches and basing fractions on estimated weights)						GROUP SYMBOLS 1/	TYPICAL NAMES
COARSE GRAINED SOILS More than half of material is larger than No. 200 sieve size 2/ (The No. 200 sieve size is about the smallest particle visible to the naked eye)	GRAVELS More than half of coarse fraction is larger than No 4 sieve size (For visual classifications, the 1/4" size may be used as equivalent to the No 4 sieve size)	CLEAN GRAVELS (Little or no fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes			GW	Well graded gravels, gravel-sand mixtures, little or no fines.
			Predominantly one size or a range of sizes with some intermediate sizes missing.			GP	Poorly graded gravels, gravel-sand mixtures, little or no fines.
		GRAVELS WITH FINES (Appreciable amount of fines)	Non-plastic fines (for identification procedures see ML below)			GM	Silty gravels, poorly graded gravel-sand-silt mixtures.
			Plastic fines (for identification procedures see CL below).			GC	Clayey gravels, poorly graded gravel-sand-clay mixtures.
	SANDS More than half of coarse fraction is smaller than No 4 sieve size	CLEAN SANDS (Little or no fines)	Wide range in grain sizes and substantial amounts of all intermediate particle sizes			SW	Well graded sands, gravelly sands; little or no fines.
			Predominantly one size or a range of sizes with some intermediate sizes missing			SP	Poorly graded sands, gravelly sands; little or no fines.
		SANDS WITH FINES (Appreciable amount of fines)	Non-plastic fines (for identification procedures see ML below)			SM	Silty sands, poorly graded sand-silt mixtures
			Plastic fines (for identification procedures see CL below).			SC	Clayey sands, poorly graded sand-clay mixtures.
FINE GRAINED SOILS More than half of material is smaller than No 200 sieve size.	IDENTIFICATION PROCEDURES ON FRACTION SMALLER THAN No 40 SIEVE SIZE						
			DRY STRENGTH (CRUSHING CHARACTERISTICS)	DILATANCY (REACTION TO SHAKING)	TOUGHNESS (CONSISTENCY NEAR PLASTIC LIMIT)		
	SILTS AND CLAYS Liquid limit less than 50		None to slight	Quick to slow	None	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity.
			Medium to high	None to very slow	Medium	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
			Slight to medium	Slow	Slight	OL	Organic silts and organic silt-clays of low plasticity.
	SILTS AND CLAYS Liquid limit greater than 50		Slight to medium	Slow to none	Slight to medium	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
			High to very high	None	High	CH	Inorganic clays of high plasticity, fat clays
			Medium to high	None to very slow	Slight to medium	OH	Organic clays of medium to high plasticity.
HIGHLY ORGANIC SOILS			Readily identified by color, odor, spongy feel and frequently by fibrous texture			Pt	Peat and other highly organic soils.

1/ BOUNDARY CLASSIFICATION: - SOILS POSSESSING CHARACTERISTICS OF TWO GROUPS ARE DESIGNATED BY COMBINATIONS OF GROUP SYMBOLS. FOR EXAMPLE GW-GC, WELL GRADED GRAVEL-SAND MIXTURE WITH CLAY BINDER.

2/ ALL SIEVE SIZES ON THIS CHART ARE U.S. STANDARD.

collectively classified as colluvium. The colluvium is probably less than 4 feet thick in most of the right abutment and the right abutment is mapped as Tertiary sediments on figure 10 even though outcrops are not present.

Exposures of Tertiary sediments on the left abutment are poor. However, outcrops of the materials are present along an irrigation ditch crossing the abutment at about elevation 6,290 feet. The Tertiary sediment outcrops are semiconsolidated and friable. The density of the GM and GW materials indicates preconsolidation due to lithostatic loading prior to Pleistocene erosion.

The relatively dense Tertiary sediments in the left abutment do not appear to have the generally excellent drainage characteristics associated with GW soils. Seepage from the irrigation ditch on the left abutment moves as overland flow across the surface of the Tertiary sediments with very little infiltration taking place. The conditions observed during the June 16, 1980, field trip indicate that most of the Tertiary sediments at the site consist of GM and SM soils with very low permeability. Lenses of GW soils within the deposits are probably horizons of relatively high permeability. The distribution, thickness, and extent of these lenses is unknown. The limited outcrops suggest that the amount of GW soils below elevation 6,200 feet may be quite small, whereas GW soils above elevation

6,300 feet on the left abutment may be more significant in terms of potential seepage paths in the abutment.

The GW and GM soils in the Tertiary sediments range from essentially noncohesive soils to slightly cohesive, nonplastic soils. The SM and CL soils are cohesive and may be remolded by hand into soft to firm casts of slightly plastic to medium plastic soil respectively. The dry shear strength of the Tertiary sediments in situ is adequate to sustain natural slopes up to 40 percent as observed on the upstream side of the left abutment.

The wet shear strength of the Tertiary sediments in situ is relatively low as is demonstrated by the presence of a number of slope failures in the vicinity of the left abutment. The largest slope failure involves about 10 acres in the NE1/4, NE1/4, section 30, T.1S., R.16W. (figure 10) and is probably a Pleistocene landslide. The landslide mass consists of a recumbent slump evidently resulting from circular arc shear failure and exhibits subdued sag ponds near the head scarp as well as relict toe bulges. The position of the relict toe bulges suggests multiple recurrent failures. The landslide mass is not stable. Other evidence of low wet shear strength in the Tertiary sediments is provided by numerous small slope failures in the form of earth flows on the left abutment. The earth flows are characterized by a small sag depression about 3 to 4 feet long and 10 to 15 feet wide and a matching toe bulge of similar dimensions. The small earth flows are shallow, being only 12 to 18 inches deep.

The foundation of the Johnson Creek site consists of Recent alluvium of unknown thickness resting on Tertiary sediments. General geologic relationships in the area suggest the alluvium consists predominantly of sand and gravel reworked from the Tertiary sediments. The alluvium would classify as GW and GM soils (table 33) but may include substantial thickness of fine-grained materials. The Recent alluvium is saturated with ground water at the elevation of Johnson Creek and presents a potential path for considerable ground-water movement.

DESIGN CONSIDERATIONS

Critical design considerations at the Johnson Creek site include potential seepage paths, stability of natural slopes, and the suitability of local materials for construction purposes.

Seepage losses are a consideration in the reservoir area and in the abutments and foundation materials at the dam site. The potential for significant seepage losses through the Tertiary sediments in the reservoir area is insignificant. The Tertiary sediments in the reservoir area would absorb water in the form of bank storage; however, overall losses to seepage would be small.

Seepage losses in the Tertiary sediments on the right and left abutments would also be small in terms of total water supply and reservoir storage capacity. However, seepage forces generated by ground-water movement in the abutment materials may present serious design considerations. Seepage forces in the semiconsolidated abutment sediments, particularly in the more permeable GW lenses, are a critical design consideration from the standpoint of:

1) material losses in the abutments due to piping; and

2) loss of shear strength and slope failure due to excessive pore pressure.

Piping. Piping is a phenomenon that occurs in soil when the water pressure due to seepage (seepage pressure) exceeds the total stress in the soil. Uplift stresses exerted on the soil particles by the seepage pressure overcome the internal friction and the total load of the soil and cause heave and displacement of the soil particles at the unrestrained soil surface. The heave is often expressed as a "boil" of the fine soil particles. It is important to recognize that an increase of the hydraulic gradient (seepage gradient) in the soil increases the seepage pressure.

If the flow associated with the boiling is sufficient to wash away the soil within the area of heave or boiling, an open cavity will be formed. The presence of the cavity causes an increase in the hydraulic gradient which in turn causes a concentration of flow into the cavity with a resultant increase in boiling and particle erosion. The cavity will begin to work its way upstream into the soil at an increasing rate of progress. The process of continued backward erosion into the soil develops an opening called a pipe and the process is termed piping. If the pipe reaches the source of water, a breakthrough will occur and the resultant rush of unrestrained flow will rapidly enlarge the pipe by erosion.

Fine-grained soil materials are most susceptible to piping failure due to the ease of transportation of the fine particles. Fine sand and silts such as the SM soils in the Tertiary sediments are particularly susceptible to piping. Clays tend to resist piping due to their low permeability and strong bonds between particles. The presence of considerable SM soil materials in the abutments coupled with the availability of potential seepage paths presented by the GW soil lenses make seepage conditions a major design consideration at the Johnson Creek site.

The foregoing discussion of piping and the potential for piping in the abutments at the Johnson Creek site emphasizes the need for a carefully conducted drilling and sampling program to determine the nature and extent of the lenses of different materials in the abutments. The drilling program should include constant head inspection tests in isolated intervals to determine the permeability of the separate lenses. Knowledge of the thickness, distribution, and permeability of the abutment materials will permit engineers to predict the major seepage paths, the hydraulic gradients that will be generated by the reservoir storage levels, and the associated seepage forces.

The foregoing data will provide the basis for design of seepage control. The basic concepts of seepage control involve:

1) reducing the flow;

2) reducing the seepage pressure; and

3) increasing the load that resists the pressure.

A conventional method of seepage control employed in the control of seepage in natural materials, such as the Tertiary sediments, is the use of drains and blankets and involves all three of the foregoing principles of seepage control.

Construction of an impermeable blanket drain on the downstream area of the abutments would reduce seepage flow, reduce seepage pressure, and increase loads resisting uplift. The blanket drain would consist of selected filter material processed from local sand and gravel in a screening and washing plant and would be placed on the prepared surface of the Tertiary sediments in the abutment. The filter blanket would be overlain by a semipermeable layer of protective fill that could be obtained directly from the Tertiary sediments. The pressure of the blanket drain would reduce the flow and decrease seepage pressures simply by increasing the length of the seepage path. The increased path length over the same elevation difference (head) results in less hydraulic gradient. The presence of a properly designed filter drain material also increases the load on the soil surface and prevents transport of soil particles by restraining the soil surface while allowing drainage to take place.

Slope Stability. The stability of slopes in an undisturbed, cohesive soil such as the Tertiary sediments depends on the shear strength of soil. The shear strength is a function of effective stress acting through the angle of internal friction. The presence of undrained water in the pores of the soil generates neutral stress under loading. The neutral stress decreases the effective stress that resists particle movement and rupture in the soil so shear strength is reduced by neutral stress. Thus, seepage water in the Tertiary sediments at the Johnson Creek site would substantially reduce the shear strength of the materials and was probably the major element in previous slope failures in the area.

Subsurface investigations such as those proposed to determine seepage potential should also include in situ sampling of the

Seismic probability or risk in Zone 2 indicates that moderately destructive earthquakes may occur. Zone 2 corresponds to a potential intensity of VII on the Modified Mercalli intensity scale of 1931. Under the recommended guidelines, dams in Seismic Zones 0, 1, and 2 are assumed to present no hazard from earthquake loading provided the dams can be shown to be stable under normal operational loads and that conventional safety margins exist.

MATERIALS SOURCES

The June 26, 1980, field work did not include an exhaustive inventory of potential construction materials in the areas outside the immediate vicinity of the potential dam site on Johnson Creek. However, local observations of the geologic materials support a number of general conclusions regarding their suitability for use in earthfill dam construction. Other general knowledge of the region indicates that adequate sources of large riprap are readily available from granitic intrusive rocks several miles from the Johnson Creek site.

Construction materials for an earthfill dam fall into two general groups; these are, pervious and impervious materials. Pervious materials include sand and gravel for concrete aggregate for filters and drains, for blankets under riprap, for drainage blankets, and for road surfacing. Impervious materials include those used for construction of the impervious core of the dam, associated cutoffs, and impervious blanket linings.

Field inspection of the Johnson Creek site indicates that the Tertiary sediments (figure 10) would provide a suitable source of impervious fill material and the Recent alluvium would be a potential source of pervious fill material for most uses. Some important engineering properties and relative desirability of the Unified Soils groups are shown on table 34. The Tertiary sediments consist of nearly equal amounts of interbedded GM and SM soils with lesser amounts of GW, MC, and CL soils present as discontinuous lenses. The Recent alluvium is estimated to consist primarily of GW and GM soils with lesser amounts of other soil groups included.

The excavation of material from the Tertiary sediments for use as impervious compacted embankment and other impervious fills and lining would result in mixing of the lenses of different materials. Use of the Tertiary sediments fanglomerate material for fill should be preceded by a careful test drilling program. The test drilling data would permit planning of the borrow pit operations to control mixing of the materials to desired soil type and rejection of unsuitable lenses such as excessive amounts of CL and ML soils. Careful pit operations may permit blending of certain soil groups to obtain soils for special uses. A blended soil might consist of GW and GM soils mixed with CL or ML soil to obtain a GC soil suitable

TABLE 34. Selected engineering properties and relative desirability for various uses for soil groups under Unified Soil Classification (Earth Manual, 1974, U.S. Bureau of Reclamation).

(NO. 1 IS CONSIDERED THE BEST)

TYPICAL NAMES OF SOIL GROUPS	GROUP SYMBOLS	IMPORTANT ENGINEERING PROPERTIES			WORKABILITY AS A CONSTRUCTION MATERIAL	RELATIVE DESIRABILITY FOR VARIOUS USES (NO. 1 IS CONSIDERED THE BEST) [illegible])									
						ROLLED EARTHFILL DAMS			CANAL SECTIONS		FOUNDATIONS		ROADWAYS		
													FILLS		
		PERMEABILITY WHEN COMPACTED	SHEAR STRENGTH WHEN COMPACTED AND SATURATED	COMPRESSIBILITY WHEN COMPACTED AND SATURATED		HOMOGENEOUS EMBANKMENT	CORE	SHELL	EROSION RESISTANCE	COMPACTED EARTH LINING	SEEPAGE IMPORTANT	SEEPAGE NOT IMPORTANT	FROST HEAVE NOT POSSIBLE	FROST HEAVE POSSIBLE	SURFACING
WELL-GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES	GW	PERVIOUS	EXCELLENT	NEGLIGIBLE	EXCELLENT	—	—	1	1	—	—	1	1	1	3
POORLY-GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES	GP	VERY PERVIOUS	GOOD	NEGLIGIBLE	GOOD	—	—	2	2	—	—	3	3	3	—
SILTY GRAVELS, POORLY-GRADED GRAVEL-SAND-SILT MIXTURES	GM	SEMIPERVIOUS TO IMPERVIOUS	GOOD	NEGLIGIBLE	GOOD	2	4	—	4	4	1	4	4	9	3
CLAYEY GRAVELS, POORLY-GRADED GRAVEL-SAND-CLAY MIXTURES	GC	IMPERVIOUS	GOOD TO FAIR	VERY LOW	GOOD	1	1	—	3	1	2	6	3	3	1
WELL-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES	SW	PERVIOUS	EXCELLENT	NEGLIGIBLE	EXCELLENT	—	—	3 IF GRAVELLY	6	—	—	2	2	2	4
POORLY-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES	SP	PERVIOUS	GOOD	VERY LOW	FAIR	—	—	4 IF GRAVELLY	7 IF GRAVELLY	—	—	5	8	4	—
SILTY SANDS, POORLY-GRADED SAND-SILT MIXTURES	SM	SEMIPERVIOUS TO IMPERVIOUS	GOOD	LOW	FAIR	4	3	—	8 IF GRAVELLY	5 EROSION CRITICAL	3	7	8	10	8
CLAYEY SANDS, POORLY-GRADED SAND-CLAY MIXTURES.	SC	IMPERVIOUS	GOOD TO FAIR	LOW	GOOD	3	2	—	5	2	4	8	7	6	2
INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS WITH SLIGHT PLASTICITY	ML	SEMIPERVIOUS TO IMPERVIOUS	FAIR	MEDIUM	FAIR	8	6	—	—	6 EROSION CRITICAL	8	9	10	11	—
INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS	CL	IMPERVIOUS	FAIR	MEDIUM	GOOD TO FAIR	5	3	—	9	3	3	10	9	7	7
ORGANIC SILTS AND ORGANIC SILT-CLAYS OF LOW PLASTICITY	OL	SEMIPERVIOUS TO IMPERVIOUS	POOR	MEDIUM	FAIR	8	8	—	—	7 EROSION CRITICAL	7	11	11	12	—
INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS	MH	SEMIPERVIOUS TO IMPERVIOUS	FAIR TO POOR	HIGH	POOR	9	9	—	—	—	8	12	12	13	—
INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS	CH	IMPERVIOUS	POOR	HIGH	POOR	7	7	—	10	8 VOLUME CHANGE CRITICAL	9	13	13	8	—
ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY	OH	IMPERVIOUS	POOR	HIGH	POOR	10	10	—	—	—	10	14	14	14	—
PEAT AND OTHER HIGHLY ORGANIC SOILS.	PT	—	—	—	—	—	—	—	—	—	—	—	—	—	—

for use as core and cutoff fill (table 34). As shown by table 34, the range of soil groups in the Tertiary sediments would provide a generally acceptable source of embankment material, particularly when considered as a pit-run mixture of GM, GC, or SC soil.

Test drilling would also be required to determine the suitability of the Recent alluvium for various pervious material uses. A test drilling program would be particularly useful in determining the magnitude of the screening effort required to produce aggregate of different grading specifications for different uses. Sample crushing and grading tests on a pilot basis may be desirable prior to final design and specifications for filters and drain materials. Use of the Recent alluvium for outer shell on the dam embankment and a bedding blanket under riprap would require less rigorous control of the grading and may draw from a slightly more diverse source area than other uses.

Uses of the alluvium as a source of concrete aggregate for outlet works and spillway construction would perhaps be the most critical use in terms of limiting properties. Field inspection reveals considerable mica content in the alluvial sands that may be the basis for rejection of the alluvium as a source of concrete sand. Similarly, the alluvial gravels contain considerable granitic metamorphic rock content. The potential for silica-reactive feldspars in the metamorphic rock gravels may require the use of special concrete additives or may result in rejection of the Recent alluvium as a source of concrete aggregate.

GEOLOGIC SUMMARY

The reconnaissance engineering-geologic examination of the potential dam site on Johnson Creek indicates the site does not present any unusual geologic hazards, foundation flaws, or seepage conditions. The site on Johnson Creek is well suited to the construction of an earthfill dam and would not require any unusual or unconventional engineering designs or construction methods.

Important design considerations at the site would be:

1) identification of pervious lenses of gravelly soils in the Tertiary sediment abutment materials and design of seepage control to prevent piping and erosion in the abutments;

2) performance of slope stability analysis for the Tertiary sediment abutments to provide a basis for stable slope design near the dam;

3) analytical evaluation of foundation seepage flows and uplift pressures and design of appropriate control measures including cutoffs, impervious upstream

blankets, downstream trench drains, drainage blankets, toe drains, and/or relief drains; and

4) location and testing of suitable sources of construction materials.

The Tertiary sediments provide a reservoir area with relatively small potential for seepage loss. There are no major faults or geologic structures that might influence foundation conditions at the dam site. The dam and reservoir site are located in Seismic Probability Zone 2 and, as such, would not require special design for seismic loading. Landslides are present in the Tertiary sediments in the reservoir and abutment areas. The existing landslides and potential for new landslides would not adversely affect engineering design considerations or construction requirements at the dam site; however, reservoir operations would probably result in renewed landslide activity in some reservoir bank areas. The anticipated landslide activity would not affect use or operation of the reservoir but should be considered prior to siting any facilities near the reservoir.

The reconnaissance engineering-geologic evaluation indicates that suitable construction materials are present at or near the potential dam site. The potential is present to combine the borrow area for the embankment with excavation of a spillway section, particularly on the left abutment area. Riprap would be readily available from potential quarry sites in the granite rocks of the Idaho batholith a few miles west of the site. Crushed aggregate from a granite quarry may be an alternative source of concrete aggregate if the Recent alluvium would not prove to be a suitable source.

Hydrology

Water supply calculations for Johnson Creek are based on correlation with records from a stream-flow gaging station located on Trail Creek. The Johnson Creek watershed is classified herein as a granitic mountain watershed with a long-term average annual run-off coefficient of 0.4483. The drainage area for the potential storage site on Johnson Creek is 37.9 square miles. Precipitation within the drainage area ranges from 16 to 60 inches per year, which results in a precipitation volume of 63,269 acre-feet per year. The product of the 63,269 acre-feet per year precipitation volume and the run-off coefficient of 0.4483 is an average annual water supply of 28,363 acre-feet per year.

RESERVOIR CAPACITY

The maximum reasonable topographic potential for storage at the Johnson Creek site would be about 150,000 acre-feet which would be substantially greater than the average annual water supply of 28,363 acre-feet. The relationship between elevation, dam height, and reservoir storage capacity at the Johnson Creek site is shown on table 35.

TABLE 35: Elevation-storage-capacity data for the Johnson Creek site.

Elevation * (in feet)	Dam height * (in feet)	Storage capacity (in acre-feet)
6,200	0	0
6,220	20	242
6,240	40	4,184
6,260	60	11,235
6,280	80	24,029
6,300	100	41,319
6,320	120	63,526
6,340	140	89,588
6,360	160	118,023
6,380	180	150,168

* Developed from 7.5-minute U.S. Geological Survey topographic map with a 40-foot contour interval.

RESERVOIR OPERATION

The effectiveness of different sizes of storage capacity in regulating the long-term average annual water supply for beneficial uses is expressed here as the percent control of the average annual supply. The percent control is the percent expression of the ratio of uncontrolled reservoir spills to the long-term average annual stream flow. Beneficial uses are irrigation (including conveyance losses and field losses) and instream uses. Irrigation requirements are based on the assumption of sprinkler irrigation of alfalfa in the upper Big Hole River basin with an average annual diversion requirement of 2.33 acre-feet per acre. The critical period for reservoir operation is based on the ten-year period of lowest recorded stream flow (1928-1937). The percent control or regulation obtained by different storage capacities on Johnson Creek is shown on table 36.

TABLE 36: Relationship between reservoir storage capacity and control of long-term average annual water supply for beneficial use during the ten-year period of low flows at the Johnson Creek site.*

Reservoir Capacity (in acre-feet)	Percent Control			
	Irrigation Only	Maximum Acres	Instream and Irrigation	Maximum Acres
5,000	83.6	3,970	85.2	3,513
10,000	94.6	3,970	95.0	3,513
15,000	95.7	3,970	95.6	3,513
20,000	95.7	3,970	95.6	3,513
30,000	95.7	5,747	95.6	5,561
40,000	95.7	5,747	95.6	5,561
60,000	95.7	5,747	95.6	5,561
80,000	95.7	10,682	95.6	10,569
100,000	95.7	11,272	95.6	10,815

* Average annual water supply is 28,363 acre-feet.

The percent control is shown for two demand assumptions. Under the column for irrigation only the reservoir would be managed to supply a maximum instream flow of 300 acre-feet per month (5 cfs) in nonirrigation months and no instream flow during the irrigation season. The irrigation only management would not satisfy instream flow requirements. The remainder of the water supply would be allocated to irrigation use, and instream flows would consist of irrigation water releases during the irrigation season.

The management assumptions for the instream and irrigation column on table 36 allocate water to satisfy minimum levels of aquatic habitat-quality flow requirements in nonirrigation months. Instream flows would be satisfied by irrigation releases in irrigation months and uncontrolled spills would be assumed to satisfy high flow requirements for instream use (but this would not always be true).

The maximum number of acres shown for both management assumptions would be the maximum acreages provided with a full water supply in every year including the year of lowest flow. The year of lowest flow is assumed to be the firm dependable water supply upon which to base project design and economics. Acreages exceeding the maximum acres would not have a firm dependable water supply available and would suffer shortages in many years.

COST ESTIMATES

Cost estimates presented herein are based on methodology and cost curves presented in Appendix A of the Series 150 Estimating Reclamation Instructions published by the Bureau of Reclamation and Bureau of Reclamation Construction Cost Trends for January 1980. The cost estimates as presented are based on generalized data and must be regarded as reconnaissance level cost estimates.

The relationship between annual costs and reservoir storage capacity is shown on figure 12. The annual costs include annual repayment based on a 6-7/8 percent discount rate, a 40-year project life, and a $20,000-per-year operation and maintenance cost. The costs apply solely to the embankment, outlet works, spillway, and appurtenant structures and do not include downstream conveyance structures for delivery of water to project lands. The spillway cost for the Johnson Creek site is based on criteria for a high-hazard dam requiring PMF discharge capacity.

Spillway costs are reduced substantially by using surcharge to store the PMF and eliminating spillway structure costs. Surcharge requires that the dam embankment be constructed to a height adequate to store the maximum storage requirement for normal operation plus the volume of the PMF. The additional embankment costs for surcharge capacity are considerably less than the costs for an

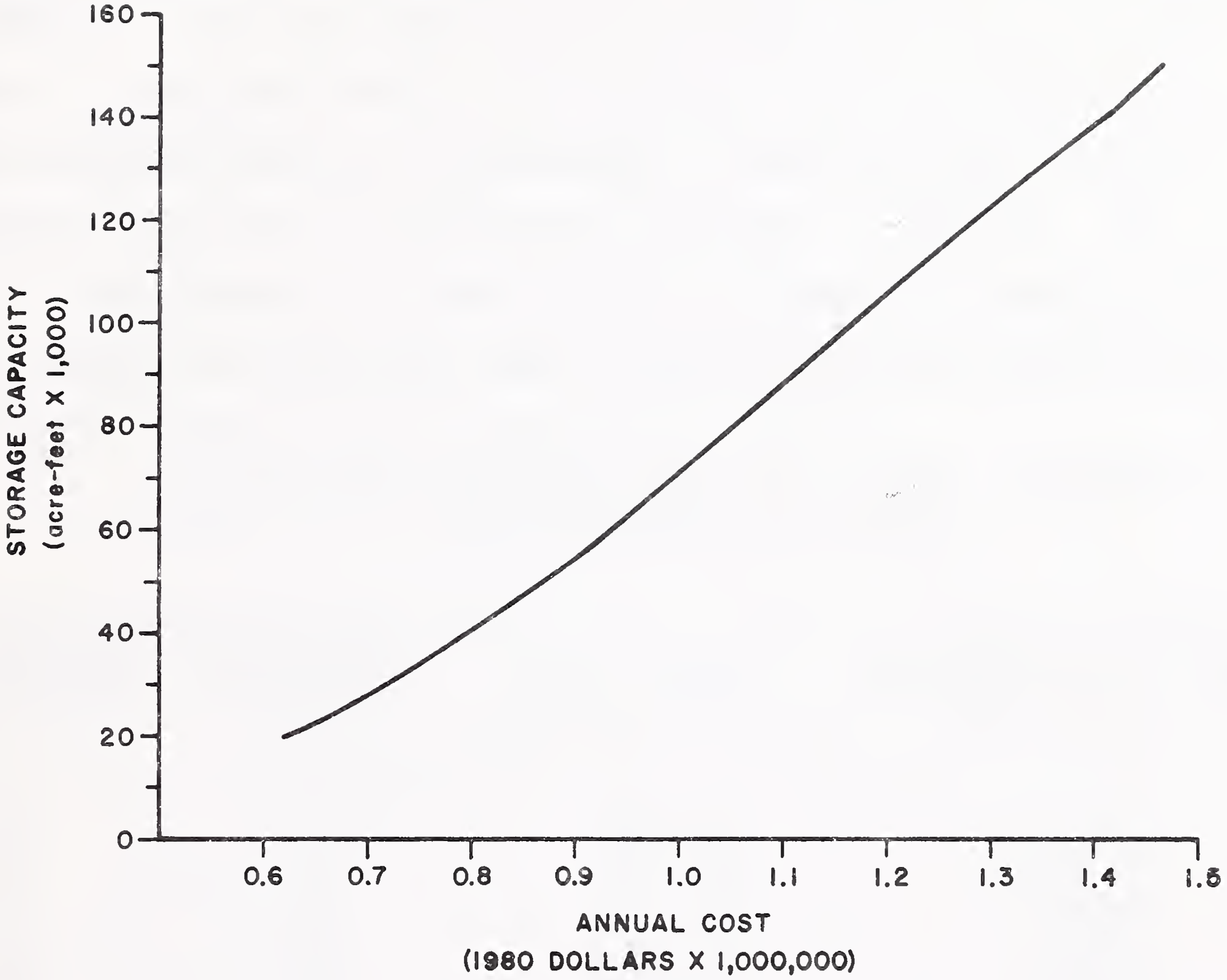


FIGURE 12. The relationship between annual costs and reservoir storage capacity at the Johnson Creek site.

emergency spillway of equivalent capacity. The annual costs versus capacity curve on table 36 includes surcharge requirements.

The estimated costs for the size of structures shown on table 36 are listed on table 37. The estimated annual costs per acre-foot for the storage capacities shown on table 36 are also shown on table 37. The costs shown on table 37 assume all costs are reimbursed by irrigation. The use of funds from the Bureau of Outdoor Recreation or the assignment of benefits to flood control, fishery, or recreation uses would reduce the cost per acre-foot for irrigation.

TABLE 37: Annual costs for different sizes of dams at the Johnson Creek site in terms of dollars per acre-foot.*

Reservoir capacity Including surcharge (in acre-feet)	Annual costs (in 1980 dollars)	Annual costs per acre-foot	
		Irrigation Only	Irrigation and Instream
5,000	473,200	$ 51	$ 58
10,000	529,300	57	65
15,000	567,100	61	69
20,000	619,500	67	76
30,000	709,800	124	128
40,000	792,700	138	143
60,000	929,300	162	167
80,000	1,056,100	99	100
100,000	1,178,000	105	109

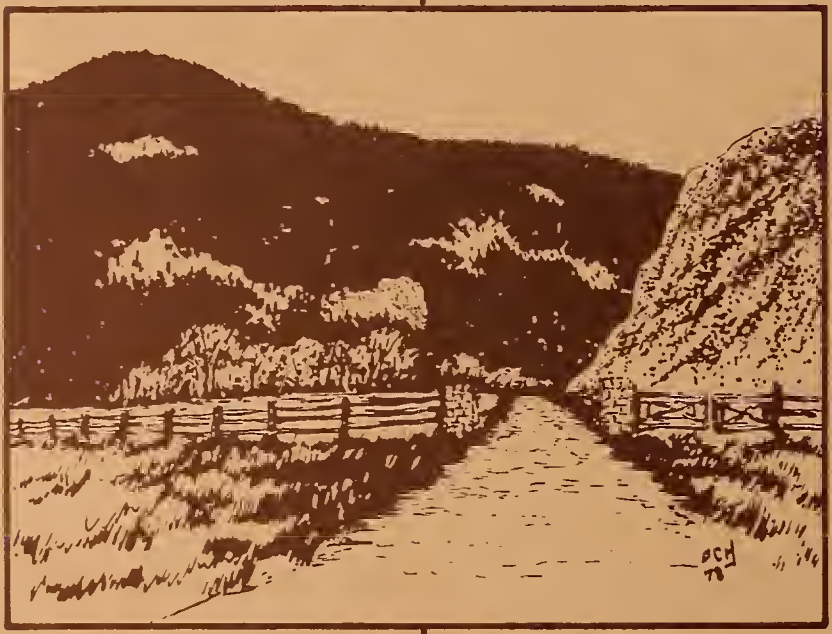
* Dam sizes are those shown on table 36.

The costs per acre-foot as shown on table 37 may be further reduced if supplemental irrigation is used. Supplemental irrigation is the delivery of less than full consumptive use requirements to a crop plant and is basically the type of irrigation currently being used in the upper Big Hole River basin. For example, if the project were designed on the basis of providing only 60 percent of the crop consumptive use requirements, the maximum acres that could be irrigated from the 5,000 acre-foot reservoir (table 36) would be 6,617 and 5,855 acres (compared to 3,970 and 3,513 acres). The costs per acre-foot (table 37) would be $51 and $58. However, the benefits gained in crop production due to supplemental irrigation may not offset the increased costs for irrigation.

REFERENCE

U.S. Bureau of Reclamation, 1974. Earth Manual, A water resources technical publication: U.S. Dept. of the Interior.

MONTANA
DEPARTMENT OF NATURAL RESOURCES
& CONSERVATION
32 South Ewing
Helena, Montana 59620



graphics by the
cartography bureau
DNR&C

50 copies of this public document were produced at an estimated cost of $6.12 per copy, for a total cost of $305.95, which includes $305.95 for printing and $.00 for distribution.